This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

NYPL RESEARCH LIBRARIES
3 3433 06640741 6

REPORTS

OF THE

COMMITTEE ON ELECTRICAL STANDARDS

APPOINTED BY

THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE,

REPRINTED BY PERMISSION OF THE COUNCIL.

REVISED BY

SIR W. THOMSON, LL.D., F.R.S., DR. J. P. JOULE, LL.D., F.R.S.,
PROFESSORS J. CLERK MAXWELL, M.A., F.R.S., AND F. JENKIN, F.R.S.

WITH

A REPORT TO THE ROYAL SOCIETY
ON UNITS OF ELECTRICAL RESISTANCE,

BY PROF. F. JENKIN, F.R.S.;

AND

THE CANTOR LECTURES,

DELIVERED BY PROF. JENKIN BEFORE THE ROYAL SOCIETY OF ARTS.

EDITED BY

PROF. FLEEMING JENKIN, F.R.S.

LONDON:
E. & F. N. SPON, 48 CHARING CROSS.
NEW YORK:
446 BROOME STREET.
1873.

REPORTS

OF THE

COMMITTEE

ON

TANDARDS OF ELECTRICAL RESISTANCE.

FIRST REPORT—CAMBRIDGE, OCTOBER 3, 1862.

EMBERS OF THE COMMITTEE:—Professor A. Williamson, F.R.S., Professor C. Wheatstone, F.R.S., Professor W. Thomson, F.R.S., Professor W. H. Miller, F.R.S., Dr. A. Matthiessen, F.R.S., Mr. F. Jenkin.

IE Committee regret that they are unable this year to submit a final Report the Association, but they hope that the inherent difficulty and importance the subject they have to deal with will sufficiently account for the delay.

The Committee considered that two distinct questions were before them, lmitting of entirely independent solutions. They had first to determine hat would be the most convenient *unit* of resistance, and second what ould be the best form and material for the *standard* representing that unit. he meaning of this distinction will be apparent when it is observed that, if e first point were decided by a resolution in favour of a unit based on rofessor Weber's or Sir Charles Bright and Mr. Latimer Clark's system, this ecision would not affect the question of construction; while, on the other and, if the second question were decided in favour of any particular arrangeent of mercury or gold wire as the best form of standard, this choice would ot affect the question of what the absolute magnitude of the unit was to be.

The Committee have arrived at a provisional conclusion as to the first queson; and the arguments by which they have been guided in coming to this ecision will form the chief subject of the present Report.

They have formed no opinion as to the second question, viz. the best form d material for the standard.

In determining what would be the most convenient unit for all purposes, th practical and purely scientific, the Committee were of opinion that the it chosen should combine, as far as was possible, the five following qualities.

1. The magnitude of the unit should be such as would lend itself to the re usual electrical measurements, without requiring the use of extravagantly h numbers of cyphers or of a long series of decimals.

2. The unit should bear a definite relation to units which may be adopted the measurement of electrical quantity, currents, and electromotive force, in other words, it should form part of a complete system for electrical asurements.

3. The unit of resistance, in common with the other units of the system, should, so far as is possible, bear a definite relation to the unit of work, the great connecting link between all physical measurements.

4. The unit should be perfectly definite, and should not be liable to require correction or alteration from time to time.

5. The unit should be reproducible with exactitude, in order that, if the original standard were injured, it might be replaced, and also in order that observers who may be unable to obtain copies of the standard may be able to manufacture them without serious error.

The Committee were also of opinion that the unit should be based on the French metrical system, rather than on that now used in this country.

Fortunately no very long use can be pleaded in favour of any of the units of electrical resistance hitherto proposed, and the Committee were therefore at liberty to judge of each proposal by its inherent merits only; and they believe that, by the plan which they propose for adoption, a unit will be obtained combining to a great extent the five qualities enumerated as desirable, although they cannot yet say with certainty how far the fourth quality, that of absolute permanency, can be ensured.

The question of the most *convenient magnitude* was decided by reference to those units which have already found some acceptance. These, omitting for the moment Weber's $\frac{\text{metre}}{\text{second}}$, were found to range between one foot of copper wire weighing one hundred grains (a unit proposed by Professor Wheatstone in 1843) and one mile of copper wire of $\frac{1}{16}$ inch diameter, and weighing consequently about 84½ grains per foot. The smaller units had generally been used by purely scientific observers, and the larger by engineers or practical electricians.

Intermediate between the two lay Dr. Werner Siemens's mercury unit, and the unit adopted by Professor W. Thomson as approximately equal to one hundred millions of absolute $\frac{\text{foot}}{\text{seconds}}$. The former is approximately equal to 371 feet, and the latter to 1217 feet, of pure copper wire $\frac{1}{16}$ inch diameter at 15° C. Both of these units have been adopted in scientific experiments and in practical tests; and it was thought that the absolute magnitude of the unit to be adopted should not differ widely from these resistances.

The importance of the *second quality* required in the unit, that of forming part of a coherent system of electrical measurements, is felt not only by purely scientific investigators* but also by practical electricians, and was indeed ably pointed out in a paper read before this Association in Manchester by Sir Charles Bright and Mr. Latimer Clark.

The Committee has thus found itself in the position of determining not only the unit of resistance, but also the units of current, quantity, and electromotive force. The natural relation between these units are, clearly, that a unit electromotive force maintained between two points of a conductor separated by the unit of resistance shall produce the unit current, and that this current shall in the unit of time convey the unit quantity of electricity.

The first relation is a direct consequence of Ohm's law; and the second was independently chosen by Weber and by the two electricians above named.

Two only of the above units can be arbitrarily chosen; when these are fixed, the others follow from the relations just stated.

Sir Charles Bright and Mr. Latimer Clark propose the electromotive force of a Daniell's cell as one unit, and choose a unit of quantity depending on this electromotive force. Their resistance-unit, although possessing what we have called the second requisite quality, and superior consequently to many that have been proposed, does not in any way possess the third quality of bearing with its co-units a definite relation to the unit of work, and has therefore been considered inferior to the equally coherent system proposed by Weber many years since, but until lately comparatively little known in this country.

Professor Weber chose arbitrarily the unit of current and the unit of electromotive force, each depending solely on the units of mass, time, and length, and consequently independent of the physical properties of any arbitrary material.

Professor W. Thomson has subsequently pointed out that this system possesses what we have called the third necessary quality, since, when defined in this measure, the unit current of electricity, in passing through a conductor of unit resistance, does a unit of work or its equivalent in a unit of time*.

The entire connexion between the various units of measurement in this system may be summed up as follows.

A battery or rheomotor of unit electromotive force will generate a current of unit strength in a circuit of unit resistance, and in the unit of time will convey a unit quantity of electricity through this circuit, and do a unit of work or its equivalent.

An infinite number of systems might fulfil the above conditions, which leave the absolute magnitude of the units undetermined.

Weber has proposed to fix the series in various ways, of which two only need be mentioned here—first by reference to the force exerted by the current on the pole of a magnet, and secondly by the attraction which equal quantities of electricity exert on one another when placed at the unit distance.

In the first or electro-magnetic system, the unit current is that of which the unit length at a unit distance exerts a unit of force on the unit magnetic pole, the definition of which is dependent on the units of mass, time, and length alone. In the second or electro-static system, the series of units is fixed by the unit of quantity, which Weber defines as that quantity which attracts another equal quantity at the unit distance with the unit force.

Starting from these two distinct definitions, Weber, by the relations defined above, has framed two distinct systems of electrical measurement, and has determined the ratio between the units of the two systems—a matter of great importance in many researches; but the electro-magnetic system is more convenient than the other for dynamic measurements, in which currents, resistances, &c. are chiefly determined from observations conducted with the aid of magnets.

As an illustration of this convenience, we may mention that the common tangent galvanometer affords a ready means of determining the value in electro-magnetic units of any current γ in function of the horizontal component of the earth's magnetism H, the radius of the coil R, its length L, and the deflection δ.

$$\gamma = \text{tang}\,\delta\,\frac{R^2 H}{L}.$$

In this Report, wherever Professor Weber's, or Thomson's, or the absolute system is spoken of, the electro-magnetic system only is to be understood as referred to. The immense value of a coherent system, such as is here described, can only be appreciated by those who seek after quantitative as distinguished from merely qualitative results. The following elementary examples will illustrate the practical application of the system.

---

* *Vide* "Application of Electrical Effect to the Measurement of Electromotive Force," Phil. Mag. 1851.

It is well known that the passage of a current through a metal conductor heats that conductor; and if we wish to know how much a given conductor will be heated by a given current in a given time, we have only to multiply the time into the resistance and the square of the current, and divide the product by the mechanical equivalent of the thermal unit. The quotient will express the quantity of heat developed, from which the rise of temperature can be determined with a knowledge of the mass and specific heat of the conductor.

Again, let it be required to find how much zinc must be consumed in a Daniell's cell or battery to maintain a given current through a given resistance. The heat developed by the consumption of a unit of zinc in a Daniell's battery has been determined by Dr. Joule, as also the mechanical equivalent of that heat; and we have only to multiply the square of the current into the resistance, and divide by the mechanical equivalent of that heat, to obtain the quantity of zinc consumed per unit of time.

Again, do we wish to calculate the power which must be used to generate by a magneto-electric machine a given current of (say) the strength known to be required for a given electric light?

Let the resistance of the circuit be determined, and the power required will be simply obtained by multiplying the resistance into the square of the current.

Again, the formula for deducing the quantity of electricity contained in the charge of a Leyden jar or submarine cable from the throw of a galvanometer-needle depends on the relation between the unit expressing the strength of current, the unit of force, and the unit magnet-pole. When these are expressed in the above system, the quantity in electro-magnetic measure is immediately obtained from the ballistic formula. In estimating the value of the various insulators proposed for submarine cables, this measure is of at least equal importance with the measure of the resistance of the conductor and of the insulating sheath; and the unit in which it is to be expressed would be at once settled by the adoption of the general system described.

These five very simple examples of the use of Weber's and Thomson's system might be multiplied without end; but it is hoped that they will suffice to give some idea of the range and importance of the relations on which it depends to those who may hitherto not have had their attention directed to the dynamical theory.

No doubt, if every unit were arbitrarily chosen, the relations would still exist in nature, and by a liberal use of coefficients experimentally determined the answer to all the problems depending on these relations might still be calculated; but the number of these coefficients and the complication resulting from their use would render such an arbitrary choice inexcusable.

A large number of units of resistance have from time to time been proposed, founded simply on some arbitrary length and section or weight of some given material more or less suited for the purpose; but none of these units in any way possessed what we have called the second and third requisite qualities, and could only have been accepted if the unit of resistance had been entirely isolated from all other measurements. We have already shown how far this is from being the case; and the Committee consider that, however suitable mercury or any other material may be for the construction or reproduction of a standard, this furnishes no reason for adopting a foot or a metre length of some arbitrary section or weight of that material.

evertheless it was apparent that, although a foot of copper or a metre of mercury might not be very scientific standards, they produced a perfectly definite idea in the minds of even ignorant men, and might possibly, with certain precautions, be both permanent and reproducible, whereas Weber's unit has no material existence, but is rather an abstraction than an entity. In other words, a metre of mercury or some other arbitrary material might possess what we have called the first, fourth, and fifth requisite qualities, to a high degree, although entirely wanting in the second and third. Weber's system, on the contrary, is found to fulfil the second and third conditions, but is defective in the fourth and fifth; for if the absolute or Weber's unit were adopted *without qualification*, the material standard by which a decimal multiple of convenient magnitude might be practically represented would require continual correction as successive determinations made with more and more skill determined the real value of the absolute unit with greater and greater accuracy. Few defects could be more prejudicial than this continual shifting of the standard. This objection would not be avoided even by a determination made with greater accuracy than is expected at present, and was considered fatal to the *unqualified* adoption of the absolute unit as the standard of resistance.

It then became matter for consideration whether the advantages of the arbitrary material standard and those of the absolute system could not be combined; and the following proposal was made and adopted as the most likely to meet every requirement. It was proposed that a material standard should be prepared in such form and materials as should ensure the most absolute permanency; that this standard should approximate as nearly as possible, in the present state of science, to ten millions of $\frac{\text{metre}}{\text{seconds}}$, but that, instead of being called by that name, it should be known simply as the unit of 1862, or should receive some other simpler name, such as that proposed by Sir Charles Bright and Mr. Latimer Clark in the paper above referred to; that from time to time, as the advance of science renders this possible, the difference between this unit of 1862 and the true ten millions of $\frac{\text{metre}}{\text{seconds}}$ should be ascertained with increased accuracy, in order that the error, resulting from the use of the 1862 unit in dynamical calculations instead of the true absolute unit, may be corrected by those who require these corrections, but that the material standard itself shall under no circumstances be altered in substance or definition.

By this plan the first condition is fulfilled; for the absolute magnitude of this standard will differ by only 2 or 3 per cent. from Dr. Siemens's mercury standard.

The second and third conditions will be fulfilled with such accuracy as science at any time will allow.

The fourth condition, of permanency, will be ensured so far as our knowledge of the electrical qualities of matter will permit; and even the fifth condition, referring to the reproduction, is rendered comparatively easy of accomplishment.

There are two reasons for desiring that a standard should be reproducible: first, in order that if the original be lost or destroyed it may be replaced; second, in order that men unable to obtain copies of the true standard may approximately produce standards of their own. It is indeed hoped that accurate copies of the proposed material standard will soon be everywhere obtainable, and that a man will no more think of producing his own standard than of deducing his foot-rule from a pendulum, or his metre from an arc of the determining an alloy with a minimum variation of resistance due to change of temperature. The object of this research was to find an alloy of which resistance-coils could be made requiring little or no correction for temperature during a series of observations. A preliminary Report on this subject is appended (A), in which the curious results of Dr. Matthiessen's experiments on alloys are alluded to, and, in particular, the following fact connected with the resistance of alloys of two metals is pointed out.

Let us conceive two wires of the two pure metals of equal length, and containing respectively the relative weights of those two metals to be used in the alloy. Let us further conceive these two wires connected side by side, or, as we might say, in multiple arc. Then let the difference be observed in the resistance of this multiple arc when at zero and 100° Cent. This difference will be found almost exactly equal in all cases to the difference which will be observed in the resistance of a wire drawn from the alloy formed of those two metal wires at zero and 100°, although the actual resistance at both temperatures will in most cases be very much greater than that of the hypothetical multiple arc.

In order to obtain a minimum percentage of variation with a change of temperature, it was consequently only necessary to make experiments on those alloys which offer a very high resistance as compared with the mean resistance of their components. The results of a few experiments are given in the Report, but these are only the first of a long series to be undertaken. Hitherto an alloy of platinum and silver is the only one of which the conducting power and variation with temperature are less than that of German silver.

Professor W. Thomson and Dr. Matthiessen were requested to examine the electrical permanency of metals and alloys. A preliminary Report on the subject by Dr. Matthiessen is appended (B), in which he shows that, after four months, one copper and two silver hard-drawn wires have altered, becoming more like annealed wires, but that no decided change has yet been detected in the great majority of the wires.

Several eminent practical electricians were requested to advise the Committee as to the form of coil they considered most suitable for a material standard, and also to furnish a sample coil such as they could recommend. Sir Charles Bright informed the Committee that he was ready to comply with the request. The point is one of considerable importance, respecting which it was thought that practical men might give much valuable information. Coils of wire may be injured by damp, acids, oxidation, stretching and other mechanical alterations. They may be defective from imperfect or uncertain insulation; and they may be inconveniently arranged, so that they do not readily take the temperature of the surrounding medium, or cannot be safely immersed in water or oil baths, as is frequently desirable. No definite conclusion as to the form of coil to be recommended, even for copies, has been arrived at.

It was resolved "That the following gentlemen should be informed of the appointment of the present Committee, and should be requested to furnish suggestions in furtherance of its object:"—

Professor Edlund (Upsala).
Professor T. Fechner (Leipzig).
Dr. Henry (Washington).
Professor Jacobi (St. Petersburg).
Professor G. Kirchhoff (Heidelberg).
Professor G. Matteucci (Turin).
Professor Neumann (Königsberg).
Professor J. C. Poggendorff (Berlin).
M. Pouillet (Paris).
Werner Siemens, Ph.D. (Berlin).
Professor W. E. Weber (Göttingen).

A letter, appended to this Report, was consequently addressed to each of these gentlemen. Answers have been received from Professor Kirchhoff and Dr. Siemens, which will be found in the Appendix. The resolution arrived at by the Committee to construct a material standard will entirely meet Professor Kirchhoff's views. The Committee have been unable entirely to adopt Dr. Siemens's suggestions; but his statements as to the accuracy with which a standard can be reproduced and preserved by mercury will form the subject of further special investigation, and the Committee will be most happy to take advantage of his kind offers of assistance.

A letter was also received from Sir Charles Bright, containing an ingenious method of maintaining a constant tension or difference of potentials. This point will probably come before the Committee at a later period, when Sir Charles Bright's suggestion will not be lost sight of.

The Committee also received, on the 29th ultimo, after the present Report had been drawn up, a letter from Dr. Esselbach, a well-known electrician, who had charge of the electrical tests of the Malta and Alexandria Cable during its submergence. In this letter Dr. Esselbach arrives at substantially the same conclusions as those recommended by the Committee. Thus, his first conclusion is "to adopt Weber's absolute unit substantially, and to derive from it, by the multiple 10^{10}, the practical unit." This practical unit is precisely that recommended by your Committee. Dr. Esselbach uses the multiple 10^{10}, starting from the $\frac{\text{millimetre}}{\text{second}}$, where your Committee recommend the multiple 10^{7}, starting from the $\frac{\text{metre}}{\text{second}}$: the result is the same.

Dr. Esselbach's next conclusion is also of great practical value. He points out that the electro-magnetic unit of electromotive force, also multiplied by 10^{10}, differs extremely little from that of the common Daniell's cell, and that, without doubt, by proper care such a cell could be constructed as would form a practical unit of electromotive force. This suggestion has the approval of the Committee. Dr. Esselbach next points out that the unit of resistance which he proposes differs very little from Dr. Siemens's mercury unit, which he, like your Committee, considers a great advantage; and the difference is, indeed, less than he supposes. He also proposes to use Weber's absolute unit for the unit of current—a suggestion entirely in accordance with the foregoing Report; and he further points out that this current will be of convenient magnitude for practical purposes. He next approves of the suggestions of Sir Charles Bright and Mr. Latimer Clark with reference to nomenclature and terminology. In the body of the Report he gives some valuable data with reference to the unit of quantity, which he defines in the same manner as your Committee. This point will be analysed in the Report which Professor W. Thomson and Mr. Fleeming Jenkin will make on the fresh determination of the absolute unit of resistance.

The Committee attach high importance to this communication, showing as it does that a practical electrician had arrived at many of the very same conclusions as the Committee, quite independently and without consultation with any of its members. Dr. Esselbach has omitted to point out, what he no doubt was well aware of, that if, as he suggests, two equal multiples of the absolute units of resistance and electromotive force are adopted, the practical unit of electromotive force, or Daniell's cell, will, in a circuit of the practical unit of resistance, produce the unit current.

Mr. Fleeming Jenkin was requested to furnish an historical summary of the various standards of resistance, but he has been unable to complete his Report in time for the present meeting.

"*The percentage decrement between* 0° *and* 100° *in the conducting power of an alloy in a solid state stands in the same ratio to the mean percentage decrement of the components between* 0° *and* 100° *as the conducting power of the alloy at* 100° *does to the mean conducting power of the components at* 100°;" or, in other words, "*the absolute difference in the observed resistance between* 0° *and* 100° *of an alloy is equal to the absolute difference between the means of the resistance of the component metals between* 0° *and* 100°."

For example, the conducting power of the hard-drawn gold-silver alloy was found equal to 15·03 at 0° (taking silver equal 100 at 0°), and decreases 6·49 per cent. between 0° and 100°. The mean decrement of the components between 0° and 100° being 29·3 per cent., the conducting power of the alloy is 14·05 at 100°, and that of the mean of the components is 62·58 at 100°. If we now calculate the percentage decrement in the conducting power of the alloy between 0° and 100° from the above data, we find it equal to 6·58 per cent., and by experiments it was found equal to 6·49 per cent. Or, taking the resistance of silver at 0°=100, and that of gold at 0°=128·3, we find the resistance of the alloy at 0°=665·3, and at 100°=711·7, and that calculated from a mean of the volumes of its components at 0°=113·2, and at 100°=159·8; therefore the absolute difference between the observed resistance at 0° and 100° is 46·4, and that between the calculated at 0° and 100°=46·8.

Knowing already, from my experiments on the electric conducting power of alloys*, that when two metals are alloyed together in any proportion, if the alloy is merely a solution of the two metals in one another, its conducting power may be approximatively foretold, and that, from the above law, it is necessary that if the conducting power of an alloy should vary between the limits of 0° and 100° to a minimum extent, the alloy itself must have a minimum conducting power as compared with that calculated from its components,—I at once foresaw that it would be useless, as was afterwards proved by the research made in conjunction with Dr. Vogt, to make any experiments with the two metal-alloys, which may be looked upon as a solution of one metal in the other, as no practical alloy would be found which would vary in its conducting power between 0° and 100° to a small extent. It must also be borne in mind that the alloy sought for must be a ductile one, capable of being drawn into wire, not too soft, as would easily be damaged by covering and winding, easily produced, and cheap in price. Bearing this in mind, we turned our attention to some three metal-alloys, thinking that we had some chance there of obtaining a good result; for it is well known that the conducting power of German-silver wire varies in such a slight extent between 0° and 100°.

It also appeared worth while to experiment with some of those alloys which may perhaps be considered chemical combinations, or to contain such, as, for instance, platinum and silver; and, on account of their other physical properties, the platinum-iridium alloys were also experimented with.

In the following Table I give the results obtained in conjunction with Dr. Vogt. The unit here taken for comparison is that of a hard-drawn silver wire at 0°. The normal wires were made of German silver, and in order to obtain their values in terms of hard-drawn silver, they were compared with the gold-silver alloy. In these experiments it was thought better first to use those pure metals which are easily obtained, so as to learn something regarding the manner in which the three metal-alloys behave, and try some alloys made of the cheaper commercial metals. As will be seen he Table, only the first part has been as yet carried out.

---

* Phil. Trans. 1860, p. 161.

TABLE.

With each series, the formula deduced from the observations for the correc- of the conducting power of the alloy for temperature is given, when λ is al to the conducting power at the temperature *t* C.)

position of alloy.	Weight.
Gold	58·3
Copper	26·5
Silver	15·2

ade from pure metals.
ard-drawn.

Length 532 mm.; diameter 0·625 mm.

T.	Conducting power. Found.
9·0	11·956
53·5	11·674
100·0	11·438

$$\lambda=12{\cdot}017-0{\cdot}0069033t+0{\cdot}0000111t^2.$$

his alloy was taken, as Karmarsch states it is the hardest and most elastic ll the gold-silver-copper alloys.

Gold	66·5
Silver	18·1
Copper	15·4

ade of pure metals.
ard-drawn.

Length 341·5 mm.; diameter 0·618 mm.

T.	Conducting power. Found.
10·95	10·5637
33·52	10·4341
55·15	10·3130
78·35	10·1846
97·52	10·0852

$$\lambda=10{\cdot}6220-0{\cdot}0056248t+0{\cdot}0000009863t^2.$$

his alloy was tried, as it corresponded to equal volumes of gold-copper gold-silver, and these again correspond to an alloy possessing the lowest ducting power of any of those made of gold-copper or gold-silver.

position of alloy.	Weight.
Copper	78·3
Silver	14·3
Gold	7·4

ade from pure metals.
ard-drawn.

Length 764 mm.; diameter 0·553 mm.

T.	Conducting power. Found.
11·0	45·591
55·5	40·333
100·0	37·560

$$\lambda=44{\cdot}472-0{\cdot}081525t+0{\cdot}0003240t^2.$$

his alloy was taken to see the effect such a combination would have.

Platinum	66·6
Iridium	33·4

ommercial alloy.
ard-drawn.

Length 244 mm.; diameter 0·682 mm.

T.	Conducting power. Found.
12·0	4·506
56·0	4·384
100·0	4·271

$$\lambda=4{\cdot}541-0{\cdot}0029307t+0{\cdot}000002724t^2.$$

his alloy was tried, as it possesses very great elasticity and does not become r on annealing. On account of these properties, as well as its permanency

in air (not oxidizing on its surface), it would serve exceedingly well making springs and contacts for electric and telegraphic apparatus.

(5) Silver .... 95·0
Platinum ...... 5·0
Made from pure silver and commercially pure platinum.
Hard-drawn.

Length 381·5 mm.; diameter 0·451

T.	Conducting power. Found.
12·0	31·173
56·0	29·550
100·0	28·068

$$\lambda = 31{\cdot}640 - 0{\cdot}039363t + 0{\cdot}00003642t^2.$$

This and the following two alloys were taken, as they probably cont chemical combinations.

(6) Silver .... 90·2
Platinum ...... 9·8
The metals employed were the same as in No. 5.
Hard-drawn.

Length 708 mm.; diameter 0·26

T.	Conducting power. Found.
9·0	17·920
54·5	17·319
100·0	16·767

$$\lambda = 18{\cdot}045 - 0{\cdot}013960t + 0{\cdot}00001183t^2.$$

(7) Silver .... 66·6
Platinum ...... 33·4
Commercial alloy.
Hard-drawn.

Length 169 mm.; diameter 0·408

T.	Conducting power. Found.
8·270	6·6850
54·00	6·5826
99·90	6·4987

$$\lambda = 6{\cdot}7032 - 0{\cdot}0022167t + 0{\cdot}000001394t^2.$$

In the following Table I have given the results in such a manner they may be easily compared.

Table.

	Conducting power at 0°.	Percentage variatio conducting power tween 0° and 10
Pure iron	....	38·2
Other pure metals in a solid state	....	29·3
Alloy 3	44·5	15·5
„ 5	31·6	11·3
„ 6	18·0	7·1
„ Gold-silver*	15·0	6·5
„ 4	4·5	5·9
„ 2	10·6	5·2
„ 1	12·0	4·8
„ German silver†	7·8	4·4
„ 7	6·7	3·1

The method and apparatus employed for the above determinations, tog with the precautions taken to ensure correct results, have already described‡. We have made only three observations between 0° and

---

[*] Phil. Mag. Feb. 1861.

[†] Phil. Trans. 1862, pt. 1.

[‡] Ibid

it was found that they gave almost exactly the same formulæ for the
rection of the conducting power for temperature as if we had taken seven
nore observations between 0° and 100°. Each of the above values for the
ducting power, at those temperatures, is the mean of three or more
ervations. It was easy to obtain the desired temperatures as a mean of
eral observations, after very little practice. I have no doubt that, in the
rse of our experiments, we shall be able to find an alloy the conducting
ver of which will decrease between 0° and 100° even less than that of silver-
tinum. The experiments are being continued, and I hope, before the next
eting of the Association, to be able to lay before you results which will
ow more light on the subject, as well as to propose an alloy with a
imum variation in its conducting power due to change of temperature,
ich may be made commercially in a cheap manner of the common com-
rcial metals, and possessing those properties which are essential that it
uld have.

Appendix B.—*On the Electrical Permanency of Metals and Alloys.*

By Dr. Matthiessen, *F.R.S.*

Having, in conjunction with Prof. Thomson, been requested by your Com-
ttee to make some experiments on this subject, we thought it advisable for
e of us to undertake some preliminary experiments in which all possible
sturbing causes were isolated. The chief of these are:—oxidation by the
ygen of the air, as well as by acids produced by the oxidation of the oil
grease with which a wire is almost always covered when drawn, as the
les in the draw-plates are generally oiled or greased; stretching during the
ocess of covering and winding; and after being wound on the bobbin, elon-
tion by expansion or contraction, owing to variations of temperature, &c.
iese, I think, have been obviated in the following manner:—The wires were
refully wound round a glass tube in order to bring them into a smaller
mpass, and after taking them off, they were placed inside wide glass tubes,
d soldered to two thick copper wires, these having been previously passed
rough corks which fitted into the ends of the glass tube; through each of
e corks a small glass tube passed, drawn out in the middle to enable it to be
awn off easily, and sealed hermetically by a lamp. The wire being soldered
the thick copper connectors, and the corks fitted into the tube, dry carbonic-
id gas was led through it for the space of about six hours, for the purpose
drying it perfectly, as well as of displacing the air contained in it; after
ich the small glass tubes were melted off at the points, when they had
en previously drawn out. Tin caps, filled with melted marine glue, were
en fitted over the corks and the ends of the tube, to prevent diffusion of the
rbonic acid and air through the corks. The whole of the tin caps outside, as
ll as those parts of the copper-wire connectors which dipped in water of
e bath in which they were placed whilst being tested, were covered with a
ick coating of marine glue.

The wires experimented with were as follows:—

Silver: hard-drawn	Cut from the same piece; pure.
Silver: annealed	
Silver: hard-drawn	Cut from the same piece, but different from 1 and 2; pure.
Silver: annealed	
Copper: hard-drawn	Cut from the same piece; pure.
Copper: annealed..........	

7. **Copper**: hard-drawn	Cut from the same piece, but diffe from 5 and 6; pure.
8. **Copper**: annealed	
9. **Gold**: hard-drawn	Cut from the same piece; pure.
10. **Gold**: annealed	
11. **Gold**: hard-drawn	Cut from the same piece, but diffe from 9 and 10; pure.
12. **Gold**: annealed	
13. **Platinum**: hard-drawn	Cut from the same piece; commer
14. **Platinum**: hard-drawn	
15. **Gold-silver alloy**: hard-drawn	Cut from same piece. Made by Me Johnson and Matthews.
16. **Gold-silver alloy**: hard-drawn	
17. **German silver**: annealed	Cut from the same piece. No. 19 ranged with longer connectors, used as normal wire with whicl rest were compared.
18. **German silver**: annealed	
19. **German silver**: annealed	

The reason why duplicates were made in each case was that, in case a them should by any cause get damaged, the experiments might be conti with the duplicate. When being tested, they were placed in a large containing from 40 to 50 litres of water. By testing the wires at 20° it found easy to keep that temperature in the bath, during the experiment 0°·1 or 0°·2.

Up to the present time, that is to say, four months since they were tested, the conducting power of the wires 1, 3, and 5 has altered, owin becoming, in all probability, partially annealed. Wire 8 has also alt materially, having decreased in conducting power 3·5 per cent.: this de ment may be possibly due to bad soldering. The differences found with other wires are so very small, that it is impossible to say whether they l altered or not; for 0°·1 or 0°·2 will account for them. It was, there thought better to wait for another two or four months before giving opinion as to whether they alter or not; for as the wires are in tubes only surrounded by carbonic acid, we can never be absolutely sure that wire has exactly the same temperature as the bath, more especially whe is considered that each time the connexion with the battery is made wire becomes somewhat heated.

If, two or four months hence, they still show no difference in their ducting powers, it is proposed to expose the one set to variations of temp ture such as may occur (for instance, from 0° to 40°), and then, shoul change occur in their conducting powers, to lead a weak current thro them, say, for a month; for it has been asserted that a current pas through wire causes a permanent change in its conducting power.

If, after these experiments the conducting power of the wires remains altered, the different forms of resistance-coils, made from those wires wl have shown themselves permanent will then be tested in order to pı which is the best form of coil for the British-Association unit.

APPENDIX C.—*On the Reproduction of Electrical Standards by Chemical Me*

By Professor WILLIAMSON, *F.R.S., and* Dr. MATTHIESSEN, *F.R.S.*

In the following Report we have discussed, more especially from a chem point of view, the relative merits of the different propositions which h been made to reproduce standards of electric resistance, and have treated tl er three heads:—

. *Those reproduced by a given length and section or weight, at a given temperature, of a pure metal in a solid state.*
[. *Those reproduced by a given length and section or weight, at a given temperature, of a pure metal in a liquid state.*
I. *Those reproduced by a given length and section or weight, at a given temperature, of an alloy.*

The points on which we shall speak will be:—

1. *On their preparation in a state of purity.*
2. *On their homogeneity and their molecular condition.*
3. *On the effect of annealing on their conducting power.*
4. *On the influence of temperature on their conducting power.*

I. *Those reproduced by a given length and section or weight, at a given temperature, of a pure metal in a solid state.*

As type of this class we have chosen copper, for it has been more exten- vely used as unit of electric resistance, both by scientific as well as by actical men, than any other metal or alloy; but what we are about to say garding copper will hold good in almost every case for all pure metals in a lid state.

1. *On its preparation in a state of purity.*—As traces of foreign metals aterially affect the conducting power of most pure metals, it is of the utmost portance that those used for the reproduction of units of electric resistance ould be absolutely chemically pure. The difficulty in obtaining absolutely re metals even by chemists is very great. Thus, for instance, Becquerel* und the conducting power of pure gold at 0° equal to 68·9, compared with at of pure silver at 0° equal to 100; whereas, under the same circumstance, atthiessen and Von Bose† found it equal to 77·9,—showing a difference of out 12 per cent. in the values observed for the conducting power of gold, epared pure by different chemists. This difference may be due to the silver t being pure, or to all of them being more or less pure. Now when we nsider that these standards are required by electricians and other physicists ho have little or no acquaintance with chemical manipulation, and that e cost of the preparation of absolutely pure metals by scientific chemists ould be very expensive on account of the time and trouble they require, e think that this fact alone constitutes a very serious drawback to their use a means for the reproduction of standards of electric resistance. From e experience which one of us has had on this subject, it is more than pro- ble that if pure metals be prepared by different chemists in the ordinary ay of business, variations in their conducting power would be found equal several per cent. Thus, copper supplied as *pure* by a well-known assayer d a conducting power equal to 92, whereas pure copper conducts at the me temperature 100‡. Again, the *pure* gold of the assayer conducts only 5·5, whereas pure gold at the same temperature would have a conducting wer equal to 73§. In order to show that the conducting power of com- ercial metals varies to a great extent, we give in the following Table (X.) e values found for that of the different coppers of commerce; and it will be ident from it, that to take a given length and weight or section of a com- ercial metal as unit, as has often been done, is very wrong, and can only ad to great discrepancies between the results of different observers.

---

* Ann. de Chim. et de Phys. (1846) t. xvii. p. 242.
† Phil. Trans. 1862, pt. 1.
‡ Proceedings of the Royal Society, vol. xi. p. 126.
§ Phil. Trans. 1860, p. 178.

c

TABLE X.[*]

(All the wires were annealed.)

	Conducting power.
Pure copper	100·0 at 15·5
Lake Superior native, not fused	98·8 at 15·5
Ditto, fused, as it comes in commerce	92·6 at 15·0
Burra Burra	88·7 at 14·0
Best selected	81·3 at 14·2
Bright copper wire	72·2 at 15·7
Tough copper	71·0 at 17·3
Demidoff	59·3 at 12·7
Rio Tinto	14·2 at 14·8

Similar variations will be found with most other metals, and we shall
examples of these further on.

2. *On its homogeneity and its molecular condition.*—It is well known
the wires of some metals require much more care in drawing than in ot
thus, copper and silver, if not annealed often enough during the proce
drawing, will often become quite brittle, and break off short when
Now, if the fracture be closely observed, it will be seen that the wire is
low; in fact, wherever it is broken, cavities will be found, and sometim
a millimetre or two in length; so that such a wire may almost be reg
as a tube with a very fine bore. The reason of this is simply that in no
nealing the wire often enough, the internal part of it becomes hard and
tle, whilst the outside remains annealed, from the heat evolved by its pa
through the holes of the draw-plates; after a time, however, the inside,
very brittle, will give way, whilst the outside is still strong enough to
the force used in drawing it through the draw-plates. These places i
wires are easily discovered on drawing the wire finer; for then at these
the wire slightly collapses, owing to the quicker elongation of the weak
by the force used in drawing. Silver and copper are the only metals
have been experimented with in this manner; we are therefore unable t
whether it may occur with the other metals. However, although no such
could be used for experiments, yet what has been shown possible to oc
such a marked extent when purposely trying to obtain such results, may
to some slight extent, especially when great care is not used, and whe
wires are drawn by different persons. This may explain why, with some
and alloys of the same preparation, conducting powers are often obt
which vary several per cent. For instance, W. Thomson[†] found the con
ing power of several alloys of copper which he had had made and test
alter considerably on being drawn finer; some of them were faulty fro
cause we have just mentioned, and, on their being drawn finer, these
showed themselves and were then cut away.

It has also been shown[‡] that when copper wire is heated to 100° for
ral days, a permanent alteration takes place in its conducting power:
with the first wire experimented on, it increased almost to the same e
as if it had been annealed. With the second wire the increment wa
nearly so large as with the first, and with the third it hardly altered a
That this is not due to one or the other of the wires being faulty in the
mentioned manner is proved,

1st, By the close agreement in the conducting powers.

---

of the Government Submarine Cable Committee, p. 335.

of the Royal Society, vol. xi. p. 126.

[‡] Phil. Trans. 1862, p

2nd, By the close agreement between the differences in the values found for the conducting powers of the hard-drawn and annealed wires. They were—

	1st wire at 0°.	2nd wire at 0°.	3rd wire at 0°.
Hard-drawn	99·5	100·0	100·3
Annealed............	101·8	102·1	102·2

The values given for the hard-drawn wires are those which were observed before the wire was heated at all.

3rd, That the same occurs with pressed wires: thus, with bismuth it was found that the pieces of the same wire behaved differently; wire 1 showing, after 1 day's heating to 100°, an increment in the conducting power of 16 per cent., whereas wire 2 increased, although a piece from the same length of wire, 9 per cent.

Again, take the case of tellurium, and taking the conducting power of each bar at first equal to 100, we find that the conducting power of bar 1 had decreased after 13 days' heating to 4, where it then remained constant, that of bar 2 after 32 days became constant at 19, and that of bar 3 after 33 days at 6.

The cause of these marked changes in the conducting power must therefore be looked for in the molecular arrangement of the wires or bars employed. In the case of copper, they may be, and probably are, due to the partial annealing of the wires; for we find that wire 1, although the conducting power increased after having been kept at 100° for several days almost to the same extent as if it had been annealed, yet, on annealing it, it only gained as follows (the results obtained with wires 2 and 3 are added):—

	1st wire at 0°.	2nd wire at 0°.	3rd wire at 0°.
Hard-drawn	99·5	100·0	100·3
After being kept several days at 100°	101·6	101·6	100·6
After annealing	101·8	102·1	102·2

The above shows that, in all probability, the annealing plays here a part, but not the whole, in the change; for otherwise why do the wires behave differently? This point will be fully discussed in another Report which will be laid before your Committee, and in which it will be shown where the hard-drawn wires become partially annealed, and annealed wires partially hard-drawn, by age.

It is a curious fact that a change in the molecular arrangement of the particles of wire of some metals which may be considered homogeneous has very little effect on its electric conducting power. Thus pure cadmium*, which when cold is exceedingly ductile, becomes quite brittle and crystalline at about 80°, and returns again to its ductile condition on cooling, shows no marked changed in its conducting power at that temperature; in fact, it behaves as if no such change had taken place. Again, when iron wire is heated in a current of ammonia it becomes perfectly brittle and crystalline, without altering its conducting power to any marked extent.

That a wire which changes its molecular condition in becoming crystalline does not necessarily materially alter in its conducting power, is an important as well as a very interesting point, and has also been proved in the case of German silver.

---

* Phil. Trans. 1862, pt. 1.

3. *On the effect of annealing on the conducting power.*—When hard-drawn wires of silver, copper, gold, &c. are heated to redness and cooled slowly, they become much softer, and on testing their conducting powers they will be found to have increased thus:—

	Silver.	Copper.	Gold.	According to
Taking the hard-drawn wire as	100·0	100·0	100·0	
The annealed will be..	107·0	102·6	101·6	Becquerel[*].
Ditto	109·0	102·3	102·0	Matthiessen and Von Bose[†].
Ditto	110·0	106·0	—	Siemens[‡].

Now there is a certain difficulty in drawing a wire which is hard-drawn; and if annealed wires be used for the reproduction of standards, the molecular condition, or perhaps the process of annealing, has an influence on the increment of the conducting power. Thus, according to Siemens[§], the difference in the conducting power between hard-drawn and annealed silver varies between 12·6 and 8 per cent., and that of copper between 6 and —0·5 per cent.; according to Matthiessen and Von Bose[||], that of silver varies between 10 and 6 per cent., and that of copper between 2·6 and 2 per cent.

Again, the annealed wires of pure metals are so soft that they would easily get damaged in covering them with silk or winding them on the bobbins, so that in using them the utmost care would have to be employed in order to prevent their getting injured.

4. *On the influence of temperature on the electric conducting power.*—It has been shown that the conducting power of most pure metals decreases, between 0° and 100°, 29·3 per cent.: pure iron has been found to form an exception to this law, its conducting power decreasing between those temperatures 38·2 per cent. If pure metals be therefore used as standards, very accurate thermometers are necessary, as an error of 0·1° in comparing two standards would cause an error in the resistance of about 0·04 per cent. Now there is great difficulty in obtaining normal thermometers; and we must bear in mind that supposing the zero-point of the thermometer is correct today, we are not at all justified in assuming that it will be so in six months time; so that we ought to redetermine the zero-point of the thermometer before using it for the above purpose. Again, it has been proved that the influence of temperature on the conducting power of wires of the same metal is not always the same[¶]. Thus, for the conducting power of annealed copper wires the following values were found:—

°	No. 1.	No. 3.
0	100·0	100·0
20	92·8	92·4
40	86·3	85·6
60	80·4	79·6
80	75·1	74·4
100	70·5	70·0

showing therefore that if standards of pure metals be used, the influence of temperature on the conducting power of each would have to be ascertained.

---

[*] Ann. de Chim. et de Phys. 1846, t. xvii. p. 242.

[†] Phil. Trans. 1862, pt. 1.

[‡] Phil. Mag. Jan. 1861.

[§] Phil. Mag. Jan. 1861.

[||] Mat[illegible] researches.

[¶] Phil. Trans. 1862, part 1.

It must also be borne in mind that it is not at all easy to maintain a standard, even in a bath of oil or water at a given temperature, for any length of time.

II. *Those reproduced by a given length and section or weight, at a given temperature, of a pure metal in a liquid state.*

The only metal which has been proposed to be used in a liquid state for the reproduction of units of resistance is mercury. We shall only have to speak of its preparation in a state of purity, and on the influence of temperature on its conducting power. For a tube, carefully filled with mercury, will certainly form a homogeneous column, and its molecular condition will always be the same at ordinary temperatures.

On its preparation in a pure state.—Although this metal is one of the most easily purified, yet the use of it as a standard is open to the same objections, although in a less degree, as have been advanced against the use of pure metals in a solid state when speaking of their preparation. We there stated that metals prepared by different chemists conducted differently. Now although the same manipulator may obtain concordant results in purifying metals from different sources, yet that by no means proves that the results of different observers purifying the same metal would show the same concordance. Thus we find that the values obtained by one experimenter* for the resistance of mercury, determined in six different tubes, varied 1·6 per cent. This difference, he says, is not greater than was to be expected. The resistances found were as follows:—

Tubes	I.	II.	III.	IV.	V.	VI.
Experiment ..	1016·52	427·28	555·38	217·73	194·70	1142·3
Calculated	1025·54	427·28	555·87	216·01	193·56	1148·9

Again, the values found for the conducting power of different preparations of pure hard-drawn gold, by the same observer†, were found equal to

78·0 at 0° 79·5 at 0° 77·0 at 0°
78·2 at 0° 78·3 at 0° 78·0 at 0°
76·8 at 0° 76·7 at 0° 77·3 at 0°

These values agree together as well as might be expected, considering that 0·01 per cent. impurity would cause these differences. Now the values obtained by different observers vary between the numbers 59 and 78.

If we now take the case of copper, the values found by the same experimenters‡ for different preparations of the pure hard-drawn metal were—

99·9 at 0° 101·0 at 0° 99·8 at 0° 99·9 at 0°
99·4 at 0° 99·4 at 0° 99·9 at 0°
99·8 at 0° 100·3 at 0° 100·0 at 0°

They were drawn by themselves, and all, with one exception, electrotype copper.

It is well known how differently the so-called *pure* copper conducts when prepared by different experimenters. In the following Table, in order to show these facts more clearly, we have given the conducting powers of the metals, taking that of silver equal 100 at 0°. Silver, copper, gold, and platinum were hard-drawn. All values given, except where the contrary i mentioned, have been reduced to 0°.

---

* Phil. Mag. Jan. 1861. The same experimenter (Dr. Siemens) states, however, in a later paper (Pogg. Ann. cxiii. p. 95), that he is able to reproduce standards of resistance by means of mercury with an accuracy equal to 0·05 per cent., but does not indicate what other precautions he takes (see remarks on the above, Phil. Mag. Sept. 1861).

† Phil. Trans. 1862, p. 12.

‡ Phil. Trans. 1862, p. 9.

	Siemens.	Lenz.	Becquerel.	Matthiessen.
Silver*	100	100	100	100
Copper	96·9	73·4	95·3	99·9
Gold	......	58·5	66·9	78·0
Cadmium	......	......	26·3	23·7
Zinc	......	......	25·7	29·0
Tin..................	......	22·6	15·0	12·3
Iron	......	13·0	13·1	14·4 at 20·4
Lead	......	10·7	8·8	8·3
Platinum	14·2	10·4	8·6	10·5 at 20·7
Mercury	1·72	3·42 at 18·9	1·86	1·65

If, now, mercury be taken as unit, we find the following values :—

	Siemens.	Lenz.	Becquerel.	Matthiessen.
Silver...............	58·20	29·24	53·76	60·60
Copper	56·40	21·46	51·23	60·55
Gold	......	17·10	37·04	47·27
Cadmium	......	......	14·14	14·42
Zinc	......	......	13·82	17·70
Tin..................	......	6·59	8·10	7·45
Iron	......	3·80	7·04	8·72 at 20·4
Lead	......	3·12	4·73	5·03
Platinum	8·25	3·04	4·62	6·36 at 20·7
Mercury............	1·00	1·00 at 18·7	1·00	1·00

A glance at the foregoing Tables will suffice to show how badly Len series agrees with the rest when mercury is taken as unit; and, in fact, obtain more concordant results if, in the above series, we take any other me as unit. These facts therefore seem to indicate that mercury is not proved to be a safe means of reproducing standards of electric resistance.

The influence of temperature on the conducting power of mercury, betwe 0° and 100°, is, comparatively speaking, small, being only 8·3 per cen whereas that of the metals in a solid state decreases between those lim 29·3 per cent. This property would, of course, render the use of very accura thermometers unnecessary; for 1° would only cause a difference in the co ducting power of about 0·08 per cent., and therefore 0·1 only 0·008 per cen so that an error of 1 or 2 tenths of a degree might almost be overlooked.

A fact has just come to our knowledge through Mr. Jenkin. He infor us that, having to make a report on the electrical apparatus in the Internatio Exhibition, he tested, amongst other things, several resistance-coils. Now found two sets of coils made by the same firm, the one exhibited in the Pr sian, the other in the English department. Both were said to be multip of the mercury unit proposed by Siemens†, and their resistances determin by comparing a coil in each set with that of a tube filled with mercu Taking each set by itself and comparing the coils in it with one another the proper combination, they were found to be perfect; in fact, the adjustment of them was perfectly accurate. When, however, Mr. Jenkin compared coils of the two sets with each other, instead of being equal, they were found to show a difference of 1·2 per cent.*

---

* This and the following Table have been copied from a paper published in the P for Sept. 1861.

Mag. Feb. 1861.

III. *Those reproduced by a given length and section or weight, at a given temperature, of an alloy.*

The alloy on which we have to speak is that composed of two parts by weight of gold and one of silver. The reason why this alloy was proposed is that the use of (say) 1 per cent. more or less gold does not materially alter its conducting power.

1. *On its preparation.*—It has been shown that the alloy may be made of commercially pure metals and have the same conducting power as that made from chemically pure ones; for the maximum differences in the conducting power between those made in different parts of the world are not greater than those of a pure metal, either in a solid or liquid state, prepared by the same experimenter. But it may be urged that part of the differences obtained by different observers are due to the different methods employed in determining their conducting powers, and therefore had the conducting power of these alloys been determined by different persons, much greater differences would have been found. In answer to this, we give, in the following Table, the determination of the conducting power of several alloys by Thomson and Matthiessen†, independently of one another. The alloys were made by Messrs. Johnson and Matthey.

Alloy.	Thomson.	Matthiessen.
1	100·0	100·05
2	95·8	95·0
3	102·9	102·7
4	100·8	99·1
5	98·1	97·7
6	89·9	92·7
7	80·6	80·06

Pure copper.	Thomson.	Matthiessen.
1	107·0	107·2
2	107·5	105·9
3	108·7	106·9
4	107·7	108·1

The differences here, with the exception of alloy 6 and copper 2, may be due to the temperature at which the observations were made not being in both cases the same; for 2 or 3 degrees' difference will account for them. The Table, however, shows that different observers do obtain the same values for the conducting power of the same wires.

The values obtained for the conducting power of the gold-silver alloy, made by different persons, of different gold and silver, are given in the following Table—

---

* This discrepancy may perhaps be attributed to some inaccuracy in the reproduction of the mercury standard.

† Proceedings of the Royal Society, Feb. 1861.

brittle, it does not materially alter in its conducting power. The same has already been proved, and mentioned in this Report, to be the case with iron and cadmium.

3. *On the effect of annealing on the conducting power of the alloy.*—When the alloy is heated to redness and cooled slowly, its conducting power was found to have increased only 0·3 per cent.—this value being the mean of eight wires annealed in different ways,—proving, therefore, that if the wires may be only partially hard-drawn, it will make but little difference in the conducting power.

4. *On the influence of temperature on the conducting power of the alloy.*—When wires of this alloy are heated from 0° to 100°, a decrement in the conducting power, amounting to 6·5 per cent., will be found. The same arguments may, therefore, be put forward in favour of the use of the alloy as a standard, as were done in the case of mercury when speaking of this property.

To sum up, therefore, the arguments in favour of and against the use of the three propositions made to reproduce standards of electric resistance, we find in favour of a pure metal in a solid state:—

1. That it appears that all descriptions of electrotype copper, when carefully drawn, have the same conducting power.

Against it:—

1. That their preparation, with the exception of the electrotype copper in a state of purity, is exceedingly difficult; so that independent persons preparing the same metal find, on comparing the conducting powers obtained for them, that they vary several per cent.

2. That the influence of annealing on their conducting powers is so great that differences may occur simply because the wires are partially hard-drawn.

3. That the influence of temperature on their conducting power is very great; so that slight errors in thermometers, or in the reading of them off, would materially affect the result.

In favour of using mercury as a means of reproducing standards the following may be said:—

1. That no molecular change can take place in the metal, nor can any alteration occur in its conducting power, on account of annealing; for its temper is always the same.

2. That the influence of temperature has only a small effect upon its conducting power.

And against it:—

1. That there is a difficulty in obtaining absolutely pure mercury; so that the results obtained by different observers show great variations.

2. That the standard tube cannot be kept full of mercury for any length of time, owing to the diffusion of impure metal, arising from the amalgamated terminals into the narrow tube; so that each time the standard has to be used, it must practically be remade.

3. If the tube be broken during the process of cleaning or otherwise, it is not yet certain with what exactitude the standard could be reproduced.

4. It is doubtful whether the resistance of a tube filled with mercury to-day will have the same resistance if filled a year hence; for we have no proof if the dimensions of the tube will not alter by being kept. It is well known that the bulbs of thermometers are liable to change, and are continually changing, in capacity.

In favour of the gold-silver alloy may be said:—

1. That this material, when prepared and drawn by different persons, was

found not to vary in its conducting power more than 1·6 per cent.; whereas the variations found with the metals in a solid state, prepared and drawn by different persons, amount to several per cent., and those found for mercury by different observers amount also in all cases to several per cent.

2. That the homogeneity and molecular condition of this alloy are always the same.

3. That the effect of annealing on the conducting power is very small, being only 0·3 per cent.; so that if a wire be partially hard-drawn, its conducting power will not suffer to any appreciable extent.

4. That the influence of temperature on its conducting power between 0° and 100°, viz. a reduction of 6·5 per cent., is smaller than either that of the metals in a solid state, viz. 29·3 per cent., or that of mercury, viz. 8·3 per cent.

And against it:—

That the conducting power may alter by age, as the physical properties of alloys are more likely to change than those of metals.

From the foregoing statements, based on facts at present known, it would appear that the best method of reproducing standards, for those who are unable to procure copies of the British Association unit of electrical resistance, is that they should make, or have made, a certain amount of the gold-silver alloy (as described in the Phil. Mag., Feb. 1861), by two or three different persons, in order to ensure a correct result, and take a given length and section or weight of it, at a given temperature, which has been found equal in resistance to the British-Association unit. We would recommend, in order further to test what we have stated in the foregoing Report, that three or more scientific men and electricians be requested to compare the resistances of pure mercury (obtained by them from the best sources they are able) and of the gold-silver alloy (made in the manner described in the Phil. Mag.) with a German-silver standard supplied to them by your Committee. If this be done, results would be obtained which would put an end to many disputes on the subject, as well as decide which of the above means is practically the best for reproducing standards of electrical resistance where no copies of the British-Association unit can be obtained.

APPENDIX D.—Professor KIRCHHOFF'S *Letter.*

To Fleeming Jenkin, Esq.

Heidelberg, June 8, 1862.

DEAR SIR,—I have the honour to acknowledge the receipt of your letter of the 31st of May, in which you inform me of the labours of the Committee appointed by the British Association, to try and bring about the general introduction of one unit of electrical resistance. I gladly respond to the invitation to express my view on the manner in which the desired object might be best attained.

To define the unit of resistance by the resistance of a wire of given dimensions of a pure metal appears to me impossible, for the reasons which have been urged by the Committee; hence, of the three proposals discussed by the Committee, there only remains two for our consideration.

1. To adopt the unit proposed by Weber; or, 2. To establish, as unit of resistance, the resistance of a column of pure mercury of given dimensions d at a given temperature.

[illegible]

[illegible] The [illegible] plan [illegible] which pies [illegible] standard [illegible] asonable cost." This plan, the execution of which I [illegible] highly sirable, might evidently be realised in all its essential points without being necessary to give the preference to one of these units over the her: it would only be necessary to measure the resistance of the normal andard in *both* units, and to add to each copy its resistance expressed in *th* units.

In choosing the metal or the alloy of which the normal standard and the pies are to be made, care must undoubtedly *be* taken that the re- stance is as unalterable as possible for *one* temperature. It is most certainly esirable that the resistance shall not vary rapidly with the temperature. his is, however, not very important, provided that the temperature of the ire can be accurately observed at any moment. [illegible] ie wires must not be coiled upon cylinders but fastened so that [illegible] reater part of their extent, they lie clear and [illegible] emperature of the surrounding air or of the non-conductor [illegible] ey may have been immersed.

You request me to point out to you any [illegible] unit of electrical resistance. I have to mention [illegible] ppeared in vol. lxxvi. of Poggendorff's 'Annalen,' [illegible] ination of the Constants on which the Intensity of Induced [illegible] lepends," and which formed the answer to [illegible] Professor Neumann, in Konigsberg, had proposed [illegible] reatise a unit of electrical resistance has not been [illegible] esistance of a wire has been measured by [illegible] nit), which was afterwards proposed by [illegible] leasurements." *Professor* W[illegible] ompare the copper wire whose [illegible] esistances he himself had determined [illegible] hereby found the resistance of my [illegible] ound it. The reason of this [illegible] erfection of the instruments which I had [illegible] my experiments the temperature was little above [illegible] periments it was about 20 [illegible] material, and therefore the same tube filled with pure mercury will certainl always conduct alike.

2nd. Change of temperature causes only a slight difference in resistance.

Against this plan it is said—

1st. That tubes cannot be made of uniform or similar wires, and tha therefore, the standard once broken is lost for ever.

2nd. That the standard tube cannot be kept full of pure mercury, owing the admixture which would take place of the solid metal used for the termina so that each time the standard has to be used it has practically to be remad

3rd. That the attempt, by most observers, to reproduce the unit for the own use would be attended with incorrect results, as is shown by the differen results obtained by different observers.

In favour of Dr. Matthiessen's alloy, as compared with wires of pure meta or with mercury, as a material for the standard, it is said—

1st. That the variations of resistance, corresponding with variations of temperature or temper, are small.

2nd. That a unit expressed in this material can be more readily and certainly reproduced than one expressed by a pure metal, because the presence of slight impurities in the component metals, or a slight chang in their proportion, does not sensibly affect the result.

Against this plan it is said that the physical properties of an alloy are more likely to change than those of a pure metal.

Against all the plans for standards, based on an arbitrary length and section of an arbitrary material, the supporters of the absolute units state that the adoption of such an arbitrary standard would lead to great confusion and complication in the measurement of all other electrical properties, and in the expression of the relation of such measurements to those of force, work, heat, &c.

This objection does not, of course, apply to the expression of the absolut unit by means of a wire of pure metal, of an alloy, or by mercury: but it i urged that no observer should ever attempt the reproduction of a standar when a copy of the proposed universal standard can possibly be obtained; and the Committee will probably endeavour to devise some plan by whic such copies of the actual material standard adopted may be easily procured a a reasonable cost.

It will be seen, from the resolutions passed, that the Committee are now engaged in investigating the degree of accuracy with which Weber's units ca be obtained, and the degree of permanency which may be expected from th use of the metal or alloy forming the material standard expressing these o other units.

The Committee will feel greatly indebted to you if you will afford them th benefit of your valuable advice and experience on the above points, and o any others which may occur to you. They also venture to hope that such standard may be selected as will give very general satisfaction; and, if approved by you, that you will kindly take an interest in procuring its genera adoption.

Personally being charged with the duty of preparing an historical summar of the various units proposed, I shall be grateful if you will favour me wit any remarks as to your own labours in this field, or if you could oblige m with references to any papers or works in which the subject is treated.

I am, Sir,
Your obedient Servant,
FLEEMING JENKIN.

PPENDIX H.—*Description of the Electrical Apparatus arranged by* Mr. Fleeming Jenkin *for the production of exact copies of the Standard of Resistance.*

This apparatus is a simple modification of that generally known as "Wheattone's bridge." It contains, however, some special arrangements, in virtue of which various practical difficulties are avoided, so that very great accuracy can be ensured with comparative ease. The usual bridge-arrangement is shown in Plate I. fig. 9, where the irregular scrolls, A, C, R, S, represent the four conductors of which the resistance is to be compared; the thick black lines show those portions of the circuit which join the coils with the four corners, X, V, Z, Y, and are supposed to have no sensible resistance in comparison with the coils; finally, the thin lines show connexions, the resistance of which in no way affects the accuracy of the comparison between the four coils. By this arrangement the four conductors, A, C, R, S, are so connected with the galvanometer, G, and the battery, B, that no current passes through the galvanometer when the conductors bear such a relation to one another that the equation $\frac{A}{C}=\frac{S}{R}$ holds good; whereas a current in one or other direction passes so soon as $\frac{A}{C}$ is greater or less than $\frac{S}{R}$*. Thus the direction and strength of the current observed serve as guides by which the resistance of any one of the conductors may be gradually adjusted by shortening or lengthening the wire, until on the completion of the circuit no deflection whatever can be observed on the galvanometer, however delicate it may be, or however powerful the battery used. When this has been done, we may be sure that the above relation exists between the four conductors. In practice, it is seldom desirable to use powerful batteries; the test is made delicate by the use of an extremely sensitive astatic galvanometer.

In speaking of the four conductors, A, C, R, S, which are generally all coils of wire of similar construction, although each fulfilling a distinct function, some difficulty often occurs in explaining readily which coil or conductor is referred to. They can of course be distinguished by letters; but this requires reference to a diagram on every occasion, and the writer has therefore been in the habit of distinguishing the four coils by names drawn from a very obvious analogy existing between this electrical arrangement and the common balance in which one weight is compared with another. The equality between the two weights on either side of a balance, when the index is at zero, depends on the equality of the arms of the balance; and if the arms are unequal, the weights required to bring the index to zero are proportional to the arms (inversely). Let A and C be called the arms of the electrical balance, while S and R are looked on as analogous to the standard weight and mass to be weighed respectively, and let the galvanometer-needle stand for the index of the balance. Then all the above statements, with respect to the weights and arms, hold good for the electrical arrangement (except that the proportion between the electrical arms and weights is direct instead of inverse). The writer therefore calls this arrangement an electric balance—A and C the arms, S the standard, and R the resistance measured†.

---

* This statement holds good also if the battery and galvanometer wires, as shown in diagram, are interchanged.

† The name of parallelogram, sometimes given to the arrangement, is objectionable, inasmuch as the relation obtaining between the four conductors is not that which exists between the four sides of any parallelogram, except in the one case of equality between all four conductors. The connexions are, however, most easily followed in a drawing when

The material which I have extensively employed in copying this measure, viz. German silver, may be classed under the same head as the expensive gold-silver alloy of Dr. A. Matthiessen, over which it has, however, the considerable advantages of a greater specific resistance, and that its resistance varies less with temperature variations.

As a preventive against alteration of resistance by the influence of the air, I have usually had the resistances made of this metal covered with a coating of silk and lac.

Intermediate between the resistances to be measured and the measure itself I have introduced resistance-scales. These contain each a series of resistances (multiples of the unit), and are so arranged that each resistance is exact when it stands stopped alone in the circuit. When carefully made, these scales may be depended on to 0·1 per cent.

Being convinced of the sufficiency of the method I have described of reproducing a standard of electrical resistance, I have the honour to suggest to you:—

1st. To recommend the universal adoption of the conducting power of mercury as unit, and of the resistance which a prism of that metal, a metre long and square millimetre section, at 0° C., opposes to a current of electricity as common unit of resistance.

2nd. To have the value of this measure ascertained, with the greatest possible exactness, in absolute units.

3rd. To have copies of this unit constructed in mercury contained in glass spirals for preservation in scientific repositories.

In the event of my suggestions being adopted, the mercury unit should be determined again with the greatest possible care, and with all the help which pure and applied science offers, and copies of it made with equal exactness.

According to a late determination by Weber, the mercury unit is only about 2½ per cent. greater than 10^{10} absolute units, or one mercury unit at —26° C. would equal 10,000,000,000 absolute units.

Since those cases in which the expression of resistances in absolute measure is of advantage in facilitating calculations occur only very seldom, and only in purely scientific exercises, a single determination of the relation of the two measures would be amply sufficient. Should the absolute unit or any multiple of it be adopted as common unit of resistance, there would still be wanted a unit for expressing the conducting powers of bodies; and mercury is indisputably the best calculated for this purpose. And for practical purposes, which in adopting a universal unit should be principally taken into consideration, it is indispensable to define the resistance-measure as a geometrical body of that material which is selected as unit of conducting power. Every other definition would not only burden unnecessarily the calculations which occur in common life, but also confuse our conception of the measure.

The reason why the arbitrary unit proposed by Jacobi (a length of copper only *approximately* defined) found no admittance into general use is to be sought in the fact that it failed to fulfil this condition, and because the conducting power of all solid bodies is too dependent on their molecular structure.

The same objection renders the adoption of the gold-silver alloy proposed by Dr. A. Matthiessen equally incapable.

Another disadvantage in the way of a solid metal unit is the impossibility to solder thick connexions into the ends of a defined length of any wire without altering its resistance.

Should the adoption of the mercury unit be deemed advisable, I would place at the service of the British Association any further information or assistance in my power.

I have the honour to be, Gentlemen,
Your most obedient Servant,
W. SIEMENS.

APPENDIX F.—*Extracts from a Letter addressed to* Professor WILLIAMSON *by* Dr. ESSELBACH.

The two objections against the practical applications of Weber's absolute unit have been sufficiently pointed out as being—

1. Its minuteness; and
2. That the electromotive force of galvanic elements does not allow of variation (as strength of current, tension, and resistance do), but that we have to accept certain constants as nature has fixed them.

I take it for granted that the standard of absolute unit would not lose in authority if a plain multiple of it were adopted. I need not point out that the French metre itself is only a submultiple, $\frac{1}{10,000,000}$th of a natural unit—the earth's quadrant. The multiple of the natural electro-magnetic unit I am about to suggest for practical use is 10^{10}, therefore very simple (which is of no little importance); and it is a multiple which leads us to those standards which are practically used.

M. Bosscha gives the electromotive force of his Daniell's cells in absolute measure as

$$1025{\cdot}80 \,.\, 10^8,$$

and calculates the one used by Mr. Joule to be

$$1045{\cdot}1 \,.\, 10^8.$$

It will therefore be practicable to determine such concentration of sulphuric acid as to make the electromotive force equal to

$$10 \,.\, 10^{10};$$

and I believe the concentration required would be very near what is actually used in telegraphy.

Resistance.—The different copies of Jacobi's étalons are well known to differ as much between each other as Daniell's cells; and if Siemens had done nothing else for galvanometry than to give us copies which agree among themselves within a quarter per cent., the progress is obvious.

Weber's copy of Jacobi's étalon is

$$598 \,.\, 10^7;$$

and that of M. Bosscha was

$$607 \,.\, 10^7$$

in absolute measure.

Other statements (of Kirchhoff and others) give a much smaller value.

In comparing Mr. Siemens's mercury standard with three copies of Jacobi's étalon in his possession, I found two of them agreeing tolerably well with each other, and with a third one copied by my friend Dr. Teddersen, at Leipzig, from the original of M. Leyser, which I took therefore to be the more correct ones. I found the absolute value of Siemens's unit to be

$$\frac{603}{660} \,.\, 10^{10},$$

or

$$1{\cdot}1 \text{ Siemens's unit} = 10^{10}.$$

We should therefore only have to multiply all observations expressed in

Siemens's units by $\frac{10^{10}}{1\cdot 1}$ to reduce them to absolute measure, and the suggested multiple for the future standard would not be far from 1·1 of Siemens's units, which every one admits to be for metallic conductors a practical unit.

For the resistance of insulating materials the figures become impracticably high; but it would be a matter of professional telegraphy to adopt, in conformity with the system, the 'resistance' 10^{10} and, besides, another 'great resistance' containing 10^{10} 'resistances.'

While the resistance of a mile of copper in an ordinary cable would be (say) 4 R. (four resistances), the insulation-resistance of a mile of cable would be about 0·04 G. R. (great or gutta-percha resistances).

My suggestion would therefore be—

1. To adopt Weber's absolute unit, and to derive from it, by the multiple 10^{10} (or 10,000,000,000), the practical unit.
2. To adopt 10^{10} of Weber's electro-magnetic units as the 'practical absolute unit' for electromotive force and resistance.
   (10 of these units would be exactly 1 Daniell's cell).
3. 1 of these units would be 1·1 of Siemens's units.
4. To allow, besides, a 'practical great unit,' viz. 10^{10} of the 'practical units,' for resistances in order to express the insulation-resistance of cables in convenient figures.
5. To allow also a 'practical small unit' of $\frac{1}{10^{10}}$ absolute units to express insulation-currents and charge-quantities of cables in convenient figures.
6. To adopt, in order to avoid confusion, for such 'practical units' a terminology as proposed by Messrs. Bright and Clark.

London, September 18, 1862.

APPENDIX G.—*Circular addressed to Foreign Men of Science.*

SIR,—I am requested to inform you that a Committee was appointed by the British Association, which met last year at Manchester, to report on Electrical Standards of Resistance.

The Committee consists of the following gentlemen:—

Professor A. W. Williamson, F.R.S. (University College, London).
Professor Charles Wheatstone, F.R.S. (London).
Professor William Thomson, F.R.S. (Glasgow).
Professor W. H. Miller, F.R.S. (Cambridge).
A. Matthiessen, Ph.D., F.R.S. (London).
Fleeming Jenkin, Esq. (London).

The Committee met on December 6th, 1861, and on April 3rd, 1862. On the latter occasion the following Resolution was passed:—

> "*Resolved*,—That the following gentlemen be informed of the appointment of the present Committee, and be requested to furnish suggestions in furtherance of its object.

Professor Edlund (Upsala).
Professor Th. Fechner (Leipzig).
Dr. Henry (Washington).
Professor Jacobi (St. Petersburg).
Professor G. Kirchhoff (Heidelberg).
Professor C. Matteucci (Turin).
Professor Neumann (Königsberg).
Professor J. C. Poggendorff (Berlin).
M. Pouillet (Paris).
Werner Siemens, Ph.D. (Berlin).
Professor W. G. Weber (Göttingen)."

I have, in consequence, the honour of addressing you the present letter.

The Resolutions passed at the two meetings are enclosed, and from them you will gather the general scope of the Committee's inquiry. I add some further explanation as to the objects and intentions of the Committee.

Great inconvenience has been felt from the absence of any generally adopted unit for the measurement of electrical resistance, and it was thought that the influence of the British Association might be successfully exerted to procure the adoption of a common standard. The present time was thought especially favourable, since, although the methods of observation have been brought to great perfection, no local units have as yet taken very deep root.

The units which up to the present time have been considered by the Committee may be classed under three heads:—

1st. A given length and weight or section of wire made of some pure metal, and observed at a given temperature, as originally proposed by Professors Wheatstone, Jacobi, and others.

2nd. Units based on Weber's and Gauss's system of absolute measurement.

3rd. A given length and section of pure mercury at a given temperature.

Whatever basis is adopted for the unit, it is proposed that the unit adopted shall be represented by one particular standard, constructed of very permanent materials, laid up in a national repository; and it has been proposed to use Dr. A. Matthiessen's gold-and-silver alloy for this purpose. The arguments which have been used for and against these systems are as follows:—

In favour of the use of a wire of some pure metal it is said—

That the plan is the simplest possible, and admits of independent observers forming their own standard.

Against this plan it is said—

1st. That even when pure, two apparently similar wires do not resist equally unless their temper or molecular condition be the same—a condition which cannot practically be ensured.

2nd. That there is reason to believe that the resistance of a given wire is not constant even at a constant temperature.

3rd. That the resistance of all pure metals varies very rapidly with the temperature.

4th. That great difficulty is found in obtaining any metal pure, and that the attempt of most persons to reproduce the unit for their own use would be attended with incorrect results. This is evidenced by the different relative results as to the resistance of pure metals published by different observers.

In favour of Weber's units it is urged—

1st. That their use will ensure the adoption of a complete system of corresponding standards for electrical currents, quantities, and tension or difference of potential.

2nd. That their use is essential in the dynamic treatment of any problem connected with electricity; for instance, in determining the heat generated, the force exerted, the work done, and the chemical action required or produced under any given circumstances.

3rd. That their use would be a simple extension of the system already universally adopted in magnetic measurements.

4th. That the unit is independent of the physical properties of any material.

Against the system it is urged that the unit cannot be determined with sufficient accuracy, and that even its approximate reproduction, where copies cannot be obtained, is difficult and expensive.

In favour of the mercury standard the following arguments are used:—

1st. No change can occur in the molecular structure or temper of the of the much larger subject of general electrical measurement. The Committee, after mature consideration, are of opinion that the system of so-called absolute electrical units, based on purely mechanical measurements, is not only the best system yet proposed, but is the only one consistent with our present knowledge both of the relations existing between the various electrical phenomena and of the connexion between these and the fundamental measurements of time, space, and mass. The only hesitation felt by the Committee was caused by doubts as to the degree of accuracy with which this admirable system could be or had been reduced to practice.

The measurements of voltaic currents, electromotive force, and quantity would offer little difficulty, provided only electrical resistance could be measured in absolute units; and for this purpose it would be sufficient that the resistance of a single standard conductor should be so determined, since copies of this standard could be multiplied at will with any desired precision, and from comparison with these copies the absolute resistance of any circuit whatever could be obtained by methods requiring comparatively little skill and well known to all electricians. The practical adoption of the absolute system was felt therefore to depend on the accuracy with which the absolute resistance of some one standard conductor could be measured; and while doubts existed on this point, it was thought premature to make any extended experiments on the application of the absolute system to voltaic currents, electromotive force, or quantity. The Committee are happy to report that these doubts have been dispelled by the success of the experiments made for the Committee by Professor J. Clerk Maxwell, Mr. Balfour Stewart, and Mr. Fleeming Jenkin, according to the method devised by Professor W. Thomson. These experiments have been actively prosecuted at King's College for the last five months with continually increasing success, as, one by one, successive mechanical and electrical improvements have been introduced, and the various sources of error discovered and eliminated.

The Subcommittee are confident that considerably greater accuracy can yet be obtained by the further removal of slight defects, the importance of which only became apparent when the main difficulties had been overcome. In order, therefore, to secure the best attainable result, and still further to test the accuracy and concordance of the experiments before taking any irrevocable step, the Committee have decided not to issue standard coils at the present Meeting; but the results already obtained leave no room for doubt that the absolute system may be adopted, and that the final standard of resistance may be constructed without any serious delay. Over-haste might eventually entail corrections as inconvenient as those which would follow an arbitrary and unscientific choice of units, and the very experiments made by the Subcommittee prove that the hesitation of many to adopt the absolute units as hitherto determined was well founded. It is certain that resistance-coils purporting to have been constructed from previous absolute determinations do not agree one with another within 7, 8, or even 12 per cent.

Before further alluding to the results obtained by the Subcommittee, it is desirable that the experiments themselves should be understood; and to this end the Committee have thought fit that a full explanation of the meaning of absolute measurement, and of the principles by which absolute electrical units are determined, should form part of the present Report, especially as the only information on the subject now extant is scattered in detached papers by W Thomson, Helmholtz, and others, requiring considerable labour to

stand. In order to make this account as clear as possible, it

t best to disregard entirely the chronological order of the

[illegible]

[illegible] purpose [illegible]

[illegible] character should [illegible]

[illegible] the absolute [illegible]

[illegible] absolute [illegible]

[illegible] Committee [illegible]

[illegible] Jr. [illegible]

[illegible] method [illegible]

[illegible] success. [illegible]

[illegible] improvements have been [illegible]

[illegible] considerable [illegible]

[illegible] greater than the [illegible]

[illegible] experiments [illegible]

[illegible] results already obtained [illegible]

[illegible] adopted, and [illegible]

[illegible] without any serious delay. [illegible]

[illegible] as convenient as those [illegible]

[illegible] limits, and the [illegible]

[illegible] the definition of [illegible]

[illegible] constructed from previous [illegible]

[illegible] results obtained [illegible]

[illegible] of the present Report, [illegible]

[illegible] and [illegible] requiring [illegible]

[illegible] take into account [illegible]

[illegible] however, [illegible]

and thermal effects produced by electricity could be neglected, such a system might perhaps be called absolute. But all our knowledge of electricity is derived from the mechanical, chemical, and thermal effects which it produces, and these effects cannot be ignored in a true absolute system. Chemical and thermal effects are, however, now all measured by reference to the mechanical unit of work; and therefore, in forming a coherent electrical system, the chemical and thermal effects may be neglected, and it is only necessary to attend to the connexion between electrical magnitudes and the mechanical units. What, then, are the mechanical effects observed in connexion with electricity? First, it has been proved that whenever a current flows through any circuit it performs work, or produces heat or chemical action equivalent to work. This work or its equivalent was experimentally proved by Dr. Joule to be directly proportional to the square of the current, to the time during which it acts, and to the resistance of the circuit; and it depends on these magnitudes only. In mathematical language this is expressed by the equation

$$W = C^2 R t, \quad \ldots \ldots \ldots \quad (3)$$

where W = the work equivalent to all the effects produced in the circuit, and the other letters retain their previous signification. This is the third fundamental equation affecting the four electrical quantities, and represents the most important connexion between them and the mechanical units. From equation (3) it follows (unless another absurd coefficeint be introduced) that the unit current flowing for a unit of time through a circuit of unit resistance will perform a unit of work or its equivalent. If every relation existing between electrical and mechanical measurements were expressed by the three fundamental equations now given, they would still leave the series of units undefined, and one unit might be arbitrarily chosen from which the three other units would be deduced by the three equations; but these three equations by no means exhaust the natural relations between mechanical and electrical measurements. For instance, it is observed that two equal and similar quantities of electricity collected in two points repel one another with a force (F) directly proportional to the quantity Q, and inversely to the square of the distance (d) between the points. This gives the equation

$$F = \frac{Q^2}{d^2}; \quad \ldots \ldots \ldots \quad (4)$$

from which it would follow that the unit quantity should be that which at a unit distance repels a similar and equal quantity with unit force. The four equations now given are sufficient to measure all electrical phenomena by reference to time, mass, and space only, or, in other words, to determine the four electrical units by reference to mechanical units. Equation (4) at once determines the unit of quantity, which, by equation (2), determines the unit current; the unit of resistance is then determined by equation (3), and the unit electromotive force by equation (1). Here, then, is one absolute or coherent system, starting from an effect produced by electricity when at rest. The units based on these four equations are precisely those called by Weber electrostatical units, although it may be observed that he chose those units without reference to what is here called the third fundamental equation, or, in other words, without reference to the idea of work, introduced into the system by Thomson and Helmholtz*.

The four equations are sufficient to determine the four units, and into this system no new relation can be introduced. The first three equations may, however, be retained, and a distinct absolute system established by substituting some other relation between electrical and mechanical magnitudes than is expressed in equation (4); and, indeed, the electrostatical system just defined is not that which will be found most generally useful. It is based on a statical phenomenon, whereas at present the chief applications of electricity are dynamic, depending on electricity in motion, or on voltaic currents with their accompanying electro-magnetic effects. Now the force exerted on the pole of a magnet by a current in its neighbourhood is a purely mechanical phenomenon. This force (f) is proportional to the magnetic strength (m) of the pole of the magnet, and to the strength of the current C; and if the conductor be at all points equidistant from the pole, or, in other words, be bent in a circle of the radius k round the pole, the force is proportional to the length of the conductor (L); it is also inversely proportional to the square of the distance (k) of the pole from the conductor, and is affected by no other circumstances than those named. Hence we have

---

* *Vide* Appendix C, § 31.

$$f = \frac{CLm}{k^2} . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

From this equation it follows that the unit length of the unit current must produce the unit force on a unit pole at the unit distance. If the equations (1), (2), (3), and (5) are adopted as fundamental, they give a distinct absolute system of units, called by Weber the electro-magnetic units. Equations (4) and (5) are incompatible one with another, if equation (2) be considered fundamental; but the electro-magnetic units have a constant and natural relation to the electrostatic units. It will be seen that in the fundamental equation (5) of the electro-magnetic system, besides the measurement of time, space, and mass, alone entering into the other equations, a fourth measurement (m) of a magnetic pole is required; but this measurement is in itself made in terms of the mechanical units, for the unit pole is simply that which repels another equal pole at unit distance with unit force. Thus in the electro-magnetic as in the electrostatic system all measurements are ultimately referred to the fundamental units of time, space, and mass. The electro-magnetic units are found much the more convenient when dealing, as we have now chiefly occasion to do, with electro-magnetic phenomena.

The relations of the electro-magnetic units one to another and to the mechanical units may be summed up as follows:—The unit current conveys a unit quantity of electricity through the circuit in a unit of time. The unit current in a conductor of unit resistance produces an effect equivalent to the unit of work in the unit of time. The unit current will be produced in a circuit of unit resistance by the unit electromotive force. The unit current flowing through a conductor of unit length will exert the unit force on a unit pole at unit distance. (In the electrostatic system all the above propositions hold good except the last, for which the following must be substituted:—the unit quantity of electricity will repel a similar quantity at the unit distance with unit force.)

It remains to be explained how electrical measurements can be practically made in electro-magnetic units. Of all the magnitudes, currents are the most easily measured, provided the horizontal force (H) of the earth's magnetism be known. Let a length (L) of wire be wound so as to form a circular coil of small section as compared with its radius (k).

Let a short magnet be hung in the centre of the coil placed in the ic meridian, as in the ordinary tangent galvanometer, and let the deflection produced by the current C be called d, then it is easily[*] proved from the fundamental equation (5) that

$$C=\frac{Hk^2}{L}\tan d \quad \ldots\ldots\ldots \quad (6)$$

Thus, where the value of H is known, a tangent galvanometer only is required to determine the magnitude of a current in electro-magnetic absolute measurement, although neither the resistance of the circuit nor the electromotive force producing the current may be known. The measurement of quantity can be obtained from that of a current by a make-and-break apparatus, or "Wippe," in a well-known manner, or by measuring the swing of a galvanometer-needle when a single instantaneous discharge is allowed to pass through it (Appendix C, § 25). If, therefore, we could measure resistance in absolute measure, the whole system of practical absolute measurement would be complete, since, when the current and resistance are known, equation (1) (Ohm's law) directly gives the electromotive force producing the current. The object of the experiments of the Subcommittee (made at King's College, by the kind permission of the Principal) was therefore to determine, in the absolute system, the resistance of a certain piece of wire, in order from this one careful determination to construct the material representative of the absolute unit with which all other resistances would be compared by well-known methods.

There are several means by which the absolute resistance of a wire can be measured. Starting from equation (3), Professor Thomson, in 1851, determined the absolute resistance of a wire by means of Dr. Joule's experimental measurement of the heat developed in the wire by a current[†]; and by this method he obtained a result which agrees within about 5 per cent. with our latest experiments. This method is the simplest of all, so far as the mental conception is concerned, and is probably susceptible of very considerable accuracy.

Indirect methods depending on the electromotive force induced in a wire moving across a magnetic field have, however, now been more accurately applied; but, before describing these methods, it will be necessary to point out the connexion between the electromotive force induced in the above manner and the fundamental equations adopted for the absolute system. The exact sense in which the terms are employed is defined in the accompanying footnote, along with some simple corollaries from those definitions[‡].

---

[*] The resultant electro-magnetic force (f) exerted at the centre of the coil by a current (C) will, by equation (5), be $f=\frac{CL}{k^2}$, and the short magnet hung in the centre will experience a couple acting in a direction perpendicular to the plane of the coil equal to $\frac{CLml}{k^2}$, where ml = the product of the strength of one of the poles into the length of the magnet, or, in other words, its magnetic moment. The strength of the couple acting perpendicularly to the axis of the magnet, when it has deflected to an angle d under the influence of the current, will be $\cos d\,\frac{CLml}{k^2}$; at the same ime the equal and opposite couple exerted on the magnet by the earth's magnetism will be $\sin d\,Hml$; hence

$$C=\frac{Hk^2}{L}\times\frac{\sin d}{\cos d}=\frac{Hk^2}{L}\tan d.$$

[†] Phil. Mag. vol. ii. ser. 4, 1851, p. 551.

[‡] *Definition* 1.—A magnetic field is any space in the neighbourhood of a magnet.

Definition 2.—The unit magnetic pole is that which, at a unit distance from a similar pole, is repelled with unit force.

A current [illegible] straight conductor [illegible] length [illegible] intensity (S) at right [illegible] units of the conductor [illegible] The force in this case [illegible] SLC, and conversely [illegible] current. Hence we have equation [illegible] exerted on a current crossing a magnet

=SLC.

Let us imagine this straight conductor to have its tw [illegible] conducting-rails of large section in connexion with the ear [illegible] R of the circuit thus formed [illegible] conductor. Let us further imagine the rails so [illegible] lines along them it moves perpendicularly to the [illegible] its own length. By experiment we know th [illegible] developed in the circuit, and that the action of the magn [illegible] current will cause a resistance (f) to the motion due to [illegible] and, by equation [illegible], we find that this resista [illegible] Let the motion be uniform, and its velocity be called V; [illegible] done in the unit of time in overcoming the resistance to mo [illegible] causes be called W; then W=VSLC. But this [illegible] than the current, and the work done by the [illegible] force be =W, or equivalent to that done in moving the con [illegible] f, but, by equation (3), W=C²R, and hence

$$R=\frac{VSL}{C} \quad . \quad . \quad . \quad . \quad . \quad . \quad .$$

[illegible] The intensity of a magnetic field at any point is equal to th [illegible] that point.

[illegible] strength (S) will produce a magnetic field [illegible] will at the unit distance from the pole [illegible] strength of the pole: for, at that distan [illegible] 2, be equal to S, and hence, by def. 3, th [illegible] would be equal to S.

[illegible] force in the field is the direction in whic [illegible] field; this is the direction which a short, balan

[illegible] magnetic field, as shown by Dr. Faraday, ma [illegible] represented by *lines* of force (each line rep [illegible] direction of the lines will indicate the directio [illegible] of lines which pass through the unit area of [illegible] intensity of the field resolved perpendicularly to th [illegible] field is one in which the intensity is equal th [illegible] Professor W. Thomson, the lines of force paral [illegible] The instrument-room, where experimen [illegible] needle is an instrument by which the direction [illegible] the field is found by a method described i [illegible] "Terrestrial Magnetism." The number of lin [illegible] perpendicularly to the dipping-needle in the [illegible] intensity, and the direction to correspond [illegible] and direction of the earth's force at a po [illegible] components, one horizontal and the ot [illegible] England for 1862 was at Kew = 3·81 [illegible] pole weighing one gramme, and free to mo [illegible] of the earth's horizontal force, acquire [illegible] metres per second. (*Vide* also Appendix [illegible] fundamental unit of length, ·17592 will b s already been shown that [illegible] the second members of equations [illegible] unknown quantities. the experiment described, the absolute resistance (R) of a wire might [illegible]. One curious consequence of these considerations is, that the [illegible] of a conductor in absolute measure is really expressed by a velo-[illegible], by equation (8), when C=1 we have R=V, that is to say, the [illegible] of a conductor may be expressed or defined as equal to the velocity which it must move, if placed in the conditions described, in order to [illegible] a current equal to the product of the length of the conductor into [illegible] of the magnetic field; or, more simply, the resistance of a circuit velocity with which a conductor of unit length must move across a mag-field of unit intensity in order to generate a unit current in the circuit. [illegible] it can be shown that this velocity is independent of the magnitude fundamental units on which the expression of the magnetic intensity of field or strength of the current is based, and hence that electrical resist-ually is measured by an absolute velocity in nature, quite independently units of time and space in which it is expressed (Appendix C, § 30). By on (8) we have $C=\frac{VSL}{R}$, but by equation (1) $C=\frac{E}{R}$, hence

$$E=VSL; \quad \dots \quad (9)$$

to say, the electromotive force produced between two ends of a t conductor moved perpendicularly to its own length and to the lines e of a magnetic field is equal to the product of the intensity of the to the length of the conductor and the velocity of the motion; or, more , the unit length of a conductor moving with unit velocity perpendicu-cross the lines of force of a magnetic field will produce a unit electro-force (or difference of potential) between its two ends. This was by made a fundamental equation, in place of equation (3), first shown mson and Helmholtz to be consistent with Weber's electro-magnetic m. These simple and beautiful relations between inductive effects and ple voltaic effects first described are well adapted to show the [illegible] herent character of the absolute system.

experiment last described, as a method of finding the absolute [illegible] nductor by measuring the velocity of motion of a straight [illegible] ely practicable; but it will be easily understood that [illegible] n, pass from this simple case to the more complex [illegible] known dimensions revolving with known velocity [illegible] tic field of known intensity. Weber, from these [illegible] solute resistance of many wires; but this method [illegible] ty of the magnetic field be known; and the [illegible] t is laborious, while its value, for the earth [illegible] nt. A method due to Professor Thomson, by which [illegible] ement is rendered unnecessary, has therefore [illegible] ments of the Subcommittee at King's College. [illegible] t, screened from the effect of the air, [illegible] ng coil, which is divided into two parts to allow [illegible] freely.

alculation it can be shown that when the coil [illegible] round a vertical e couple exerted on a magnetic needle of the moment [illegible] when deflected angle d, will be $\frac{L^2VH}{4l^2R}\sin d\cos d$.

The equal and opposite couple caused by the earth's magnetism will be $Hml \sin d$. Hence

$$\tan d = \frac{L^2 V}{4k^2 R}$$

or

$$R = \frac{L^2 V}{4k^2 \tan d}, \qquad \ldots\ldots\ldots\ldots \qquad (10)$$

an equation from which the earth's magnetic force and the moment of the suspended magnet have been eliminated, and by which the absolute resistance (R) can be calculated in terms of the length (L), the velocity (V), the radius (k), and the deflection (d). The resistance thus calculated is expressed in electro-magnetic absolute units, because equation (10) is a simple consequence of equations (1), (3), and (5)—fundamental equations in the electro-magnetic system. The essence of Professor Thomson's method consists in substituting, by aid of the laws of electro-magnetic induction, the measurements of a velocity and a deflection for the more complex and therefore less accurate measurements of work and force required in the simple fundamental equations. But, however simple in theory the method may be, the practical determination of the absolute resistance of a conductor by its means required great care and very numerous precautions,—some of an obvious character, while the need of others only became apparent during the course of the experiments.

The apparatus consisted of two circular coils of copper wire, about one foot in diameter, placed side by side, and connected in series; these coils revolved on a vertical axis, and were driven by a belt from a hand-winch, fitted with Huyghens's gear to produce a sensibly constant driving-power. A small magnet, with a mirror attached, was hung in the centre of the two coils, and the deflections of this magnet were read by a telescope from the reflection of a scale in the mirror. A frictional governor controlled the speed of the revolving coil. The details and a drawing of the apparatus are given in Appendix D and Plate II.; but a short account may fitly be given here of the points of chief practical importance, the difficulties encountered, and the improvements still desirable.

It is essential that the dimensions of the coil be very accurately known, that the axis on which it revolves should be truly vertical, and that, except in the coil itself, no currents affecting the position of the magnet be induced in any part of the apparatus. To measure the angular deflection the distance of the scale from the mirror is required, and the scale must be truly perpendicular to the line joining its middle point with the suspension-fibre. All these conditions were fulfilled without difficulty; but the scale by the reflection of which the deflections were measured was, towards the end of the experiments, found not to be very accurately divided; and although a correction for this inaccuracy has been applied in the calculations, an improvement can in future experiments be effected by the use of a more perfect scale. The magnet was suspended by a single silk fibre, eight feet long, inside a wooden case, and by suitable adjustments was brought very carefully to the centre of the coils. The whole suspended system was so screened from currents of air, and so well protected from vibration, that when the coil revolved at its full speed of 350 revolutions per minute, the reflection in the mirror was as clear and undisturbed as when the coil was at rest. The torsion of the long fibre was determined by experiment, and the slight necessary corrections applied in the calculations. The Huyghens's gearing for the driving hand-winch was somewhat roughly constructed, and could certainly oved; nevertheless there was little difficulty in maintaining a sensibly constant driving-power for twenty minutes at a time. The speed of the coil was controlled by a frictional governor of novel form, designed by Mr. Jenkin for another purpose, and lent for the experiments in question. The action of this governor, combined with that of the driving-gear, was such that in many experiments the oscillations in deflection due to a change of speed were not so great as those due to the passage of steamers in the river when all parts of the apparatus were at rest; so that the deflections during twenty minutes could be quite as accurately observed as the slightly imperfect zero-point from which they were measured. Still better results are expected with a larger governor, made specially for the apparatus, on the joint plans of Professor Thomson and Mr. Jenkin. The oscillations produced by the passage of steamers on the Thames at no great distance from the place of experiments were of very sensible magnitude; and although by carefully observing the limit of every oscillation during every experiment the error due to this cause was in great part eliminated, it is desirable that any future experiments should be conducted in some spot free from all local magnetic disturbance.

The speed of the coil was determined by observing on a chronometer the instant at which a small gong was struck by a detent released once in every hundred revolutions. Mr. Balfour Stewart's skill in this kind of observation enabled him thus to determine the velocity with great accuracy, especially as the observations frequently lasted for twenty minutes without material alteration in the speed.

During the operation of coiling the wire, the circumference of the core and of each successive layer was carefully measured by means of a steel riband applied first to the coil, and then to a standard scale, allowance being made for the half thickness of the steel. From this the mean radius and depth of the coil and the effective length of the wire were determined. It was considered advisable, however, in order to check any error in counting the number of windings of the coil, to measure the length of the wire when uncoiled. This was effected without stretching the wire, in a manner amusing from its simplicity. At the conclusion of the experiments, the wire to be measured was uncoiled in the Museum at King's College and lay in awkward bends on the planked floor. The straight planks formed an obvious contrast to the crooked wire, and a joint between the planks was found where the opening was just sufficient to hold the wire when pushed into this little groove. Held in this way, the wire when measured was quite straight, and yet was never stretched.

No other measurements than those already described are required by the simple theory; but this theory, as hitherto stated, stands in need of various slight corrections. The currents induced by the earth's magnetism are modified by the currents induced by the little suspended magnet, and also by the induction of the coil on itself. The force deflecting the magnet is also modified by the lateral distance of the coils from the vertical axis. An elaborate analysis of the corrections required on these grounds was made by Professor Maxwell (Appendix D), and to allow of these corrections, the moment of the suspended magnet was measured, and the position of every turn of the copper coil carefully observed. An experimental determination of the induction of the coil on itself, by a method due to Professor Maxwell, agreed with the calculated correction within one quarter per cent.

The resistance of the copper coil measured by these laborious experiments varied each day, and during each day, according to the temperature; and, moreover, this temperature could at no time be determined with sufficient accuracy. It was therefore intended that at each experiment a small Germannumeration of objects to be pursued by the Committee, if reappointed at the resent Meeting:—

1st. The experiments on the determination of the absolute unit of resistance will be continued.

2nd. Immediately on the conclusion of these experiments, equal standards, onstructed of such metals as promise the greatest constancy, will be deposited at Kew, where the permanence of their equality will be rigorously ested.

3rd. Unit resistance-coils of the best known construction will be issued to he public.

4th. The experiments already begun on the permanence of the electrical resistance of wires and alloys under various circumstanees will be continued and extended.

5th. The experiments on the reproduction of standards by chemical means will be continued.

6th. Experiments on the best construction of gauges of electromotive force or difference of potential, and on electrometers, will be continued.

7th. A standard galvanometer, for the measurement of currents in absolute measure, will be constructed, and electro-dynamometers for the same purpose compared with the standard instrument, and issued to the public.

8th. Experiments on the ratio between the electrostatic units and the electro-magnetic units will be undertaken.

9th. Experiments will be made on the development of heat in conductors of known absolute resistance with currents of known absolute magnitude. The results of this experiment will give, by equation (3), a new and very accurate determination of the mechanical value of the unit of heat.

The conclusion of the experiments on absolute resistance, and the adoption of the absolute system as the basis of all electrical measurement, will, it is hoped, allow considerable progress to be made in most of these researches.

APPENDIX A.—*On the Electrical Permanency of Metals and Alloys.*

By A. MATTHIESSEN, *F.R.S.*

The following are the results obtained with the metals and alloys described in Appendix B of the Report on Standards of Electrical Resistance by your Committee:—

The wires to be experimented on were—

1. Silver: hard-drawn	Cut from the same piece; pure.
2. Silver: annealed	
3. Silver: hard-drawn	Cut from the same piece, but different from 1 and 2; pure.
4. Silver: annealed	
5. Copper: hard-drawn	Cut from the same piece; pure.
6. Copper: annealed	
7. Copper: hard-drawn	Cut from the same piece, but different from 5 and 6; pure.
8. Copper: annealed	
9. Gold: hard-drawn	Cut from the same piece; pure.
10. Gold: annealed	
11. Gold: hard-drawn	Cut from the same piece, but different from 9 and 10; pure.
12. Gold: annealed	

13. Platinum: hard-drawn .... } Cut from the same piece; commercial.
14. Platinum: hard-drawn .... }
15. Gold-silver alloy: hard-drawn } Cut from same piece. Made by Messrs Johnson and Matthey.
16. Gold-silver alloy: hard-drawn }
17. German silver: annealed.... } Cut from the same piece. No. 19 arranged with longer connectors, and used as normal wire with which the rest were compared.
18. German silver: annealed.... }
19. German silver: annealed.... }

These were first tested on May 9th, 1862, and at intervals between that date and June 14th, 1863, when they were last tested. During the time when not used, they were hung up in a room where in the winter a fire was kept all day, so that the temperature may have varied at times some 10 or 12 degrees in the twenty-four hours.

The following Table contains the results of the first and last comparisons. I have taken the conducting power in the first in all cases equal to 100 as compared with No. 19; in the last I have assumed that the conducting power of No. 15 has remained unaltered:—

	Conducting powers found, as compared with No. 19 = 100.				Conducting power found, as compared with No. 15 = 100.	
	1.		2.		3.	
	May 9, 1862.	T.	June 14, 1863.	T.		T.
1. Silver: hard-drawn	100·00	20·2	103·700	20·0	103·915	20·0
2. Silver: annealed	100·00	20·2	99·740	20·1	99·947	20·1
3. Silver: hard-drawn	100·00	20·2	102·590	20·2	102·807	20·2
4. Silver: annealed	100·00	20·2	99·825	20·0	100·031	20·0
5. Copper: hard-drawn	100·00	20·1	100·040	20·2	100·248	20·2
6. Copper: annealed	100·00	20·1	99·807	20·0	100·015	20·0
7. Copper: hard-drawn	100·00	20·0	99·941	19·8	100·149	19·8
8. Copper: annealed	100·00	20·0	95·358	20·4	95·556	20·4
9. Gold: hard-drawn	100·00	20·0	99·838	20·2	100·045	20·2
10. Gold: annealed	100·00	20·0	99·855	20·0	100·062	20·0
11. Gold: hard-drawn	100·00	20·0	99·662	20·2	99·869	20·2
12. Gold: annealed	100·00	20·0	99·670	20·3	99·877	20·3
13. Platinum: hard-drawn	100·00	20·0	99·744	20·2	99·951	20·2
14. Platinum: hard-drawn	100·00	20·0	99·792	20·2	99·999	20·2
15. Gold-silver alloy: hard-drawn	100·00	20·0	99·793	20·2	100·000	20·2
16. Gold-silver alloy: hard-drawn	100·00	19·9	99·756	20·3	99·963	20·3
17. German silver: annealed	100·00	20·3	99·955	20·0	100·162	20·0
18. German silver: annealed	100·00	20·3	99·938	20·0	100·145	20·0
19. German silver: annealed	......	......	......	......	100·217	20·2

From the above it would appear that if the conducting power of No. 19 has remained constant, that of all the others has altered; but supposing such to be the case, it will be found on comparing the values that the conducting powers have all altered in a like extent. Is it probable? Is i not more probable that the conducting power of the German silver ha changed, than that that of all the others should have altered in the sam degree? If that of the gold-silver alloy (No. 15) be called 100·00 instead o 99·793, then, as will be seen from column 3, very few show any change i

: conducting power. Those which show no sensible change are as ws:—

	Values taken from column 3.
No. 2. Silver: annealed	[illegible]47
No. 4. Silver: annealed	[illegible]31
No. 6. Copper: annealed	[illegible]15
No. 9. Gold: hard-drawn	[illegible]45
No. 10. Gold: annealed	[illegible]62
No. 13. Platinum: hard-drawn	[illegible]51
No. 14. Platinum: hard-drawn	[illegible]99
No. 15. Gold-silver alloy: hard-drawn	[illegible]
No. 16. Gold-silver alloy: hard-drawn	[illegible]63

le differences in the above are probably due to temperature; for as the s are in tubes filled with carbonic-acid gas, we can never be absolutely that wire has exactly the same temperature as the bath. In properly resistance-coils this source of error is materially diminished, and in experiments which are about to be made to further test the electrical anency of metals and alloys this source of error will be almost entirely ited. It may be here again mentioned, that the reason of placing the in glass tubes filled with carbonic-acid gas was to obviate the oxidation e metal or alloy by the oxygen of the air, or from the acids produced by xidation of the oil or fat with which the wires are covered when drawn, e holes in the draw-plates are generally oiled or greased, &c.
ose whose conducting-power has changed are as follows:—

	Values taken from column 3.
No. 1. Silver: hard-drawn	103·915
No. 3. Silver: hard-drawn	102·807
No. 5. Copper: hard-drawn	100·248
No. 7. Copper: hard-drawn	100·149
No. 8. Copper: annealed	95·556
No. 11. Gold: hard-drawn	99·869
No. 12. Gold: annealed	99·877
No. 17. German silver: annealed	100·162
No. 18. German silver: annealed	100·145
No. 19. German silver: annealed	100·227

e cause of the change in the conducting power of [illegible] is undoubtedly due to their becoming somewhat annealed [illegible] 3 the alteration may be attributed to faulty [illegible] ng power of the German silver experimented with [illegible] that all German silver will do so; for we find [illegible] ot altered, but Nos. 11 and 12 (which were cut from [illegible] a different one from the one from which [illegible] altered. Further experiments are, however, required [illegible] metals and alloys given above as constant [illegible] o or not.

hröder van der Kolk states* that the [illegible] rgoes a change when even weak currents [illegible] rder to see whether that of the above [illegible] following experiment was arranged. [illegible] connected together, and a current from [illegible] ass through them day and night for [illegible]

---

prà, p. 16; and Brit. Assoc. Report, 1862, [illegible] every morning and evening, and the dilute sulphuric acid renewed. The experiment was carried out soon after June 14, 1863. In the subjoined Table the conducting powers are given as found before and after the trial, compared with No. 19.

	Conducting power observed, as compared with No.19=100.			
	Before.	T.	After.	T.
No. 1........	103·700	20·0	103·775	20·2
No. 2........	99·740	20·1	99·733	20·2
No. 5........	100·040	20·2	100·045	20·2
No. 6........	99·807	20·0	99·865	20·0
No. 9........	99·838	20·2	99·860	20·2
No. 10........	99·855	20·0	99·807	20·2
No. 13........	99·744	20·2	99·766	20·2
No. 15........	99·793	20·2	99·762	20·2
No. 17........	99·955	20·0	99·926	20·2

From the above numbers it will be seen that the conducting power has not changed, the differences in the values being in all probability due, as above stated, to temperature.

If the passage of a current really altered the conducting power of a wire, then of what use would resistance-coils be? The above experiments prove that a much stronger current than is used for testing the resistance of a wire has no effect on it.

APPENDIX B.—*On the Variation of the Electric Resistance of Alloys due to Change of Temperature.* *By* A. MATTHIESSEN, *F.R.S.*

IN the Appendix to the Report of your Committee read at the Meeting held last year, I gave a Table containing the results of experiments with some alloys, made with a view to find out the alloy whose conducting power decreases least with an increase of temperature. With the same apparatus, &c., I have, in conjunction with Dr. C. Vogt, experimented with the following alloys.

(With each series the formula deduced from the observations for the correction of the conducting power for temperature is given, where λ is equal to the conducting power at the temperature $t°$ C. Silver (hard-drawn) is taken at 0°=100.)

Composition of alloy by weight.		Length 226 mm.; diameter 0·470 mm.	
		T.	Conducting power.
(1) Gold..........	95·3	12·0	2·3573
Iron..........	4·7	56·0	2·3138
Made from pure metals.		100·0	2·2798
Hard-drawn.			

$$\lambda=2{\cdot}3708-0{\cdot}0011555t+0{\cdot}000002454t^2.$$

		Length 284 mm.; diameter 1·217 mm.	
		T.	Conducting power.
(2) Gold..........	95·0	15·0	2·0819
Iron..........	5·0	57·5	2·0424
Hard-drawn.		100·0	2·0067

$$\lambda=2{\cdot}0967-0{\cdot}0010057t+0{\cdot}000001052t^2.$$

This and the two following alloys were made by Messrs. Johnson and Matthey. No. 2 was made to check the results obtained with No. 1; fo

e given with Nos. 3 and [illegible]
e with No. 1. That this [illegible]
. a very curious fact [illegible]
mer, for in no other sense [illegible]
e may be attributed [illegible]
l alloys of gold and iron
os. 3 and 4 are very [illegible]

Gold .... [illegible]
Iron .... [illegible]
ard-drawn.

λ=[illegible]

Gold........... [illegible]
Iron........... [illegible]
ard-drawn.

λ=[illegible]

Silver ...... [illegible]
Palladium . . [illegible]
ade by Messrs. Johnson and
Matthey.
ard-drawn.

λ=[illegible]

his alloy was formerly [illegible]
tested, as it appeared [illegible]

Copper.......... [illegible]
Zinc........... [illegible]
ade from pure metals.
ard-drawn.

λ= [illegible]

Copper... [illegible]
Zinc... [illegible]
ade from [illegible]
ard-drawn.

ese alloys are [illegible]

It seemed very desirable to test the influence of temperature on the alloy, as it was proposed by Jacobi as a unit of electric resistance.

(8) Copper .... 90·3
Tin .... 9·7
Made from pure metals.
Hard-drawn.

Length 322·5 mm.; diameter 0·524 mm.

T.	Conducting power.
15·43	12·058
23·40	11·990
40·35	11·852
54·75	11·737
69·78	11·619
84·66	11·499
98·70	11·391

$$\lambda=12{\cdot}186-0{\cdot}0084168t+0{\cdot}000003700t^2.$$

(9) Copper .... 89·7
Tin .... 10·3
Made from pure metals.
Hard-drawn.

Length 429 mm.; diameter 0·627 mm.

T.	Conducting power.
11·0	10·1386
55·5	9·8710
100·0	9·6526

$$\lambda=10{\cdot}212-0{\cdot}0068043t+0{\cdot}00001210t^2.$$

These alloys are given, as they approach in composition to that of ordinary gun-metal.

(10) Gun-metal (Austrian).
Copper.
Zinc.
Iron.
A specimen obtained through the kindness of Mr. F. Abel.
Hard-drawn.

Length 904·5 mm.; diameter 0·650 mm.

T.	Conducting power.
13·0	26·336
56·5	24·056
100·0	22·121

$$\lambda=27{\cdot}084-0{\cdot}058750t+0{\cdot}00009116t^2.$$

The conducting power of this alloy increased by heating to 100° for one day 5·7 per cent.—a larger increment than has been observed with any alloy. Generally, the conducting power of an alloy either remains constant or only varies 0·1 or 0·2 per cent. under the same conditions.

(11) Proof gold.
Hard-drawn.

Length 1564 mm.; diameter 0·525 mm.

T.	Conducting power.
15·0	68·969
57·5	60·179
100·0	53·387

$$\lambda=72{\cdot}548-0{\cdot}24692t+0{\cdot}0005531t^2.$$

(12) Standard silver.
Hard-drawn.

Length 2328 mm.; diameter 0·525 mm.

T.	Conducting power.
12·0	78·015
56·0	69·301
100·0	61·949

$$\lambda=80{\cdot}628-0{\cdot}22196t+0{\cdot}0003518t^2.$$

In the following Table I have given the results here obtained, with those of last year, in such a manner that they may be easily compared:—

	Conducting power at 0°.	Percentage decrement in conducting power between 0° & 100°.
Pure iron *	16·81	39·2
Pure thallium *	9·16	31·4
Other pure metals in a solid state	....	29·3
Gold, with 15 p.c. iron	2·76	27·9
Proof gold	72·55	26·4
Standard silver	80·63	23·2
Gun-metal (Austrian)	27·08	18·3
Gold, with 10 p.c. iron	2·06	17·5
Gold, with 14·3 p.c. silver and 7·4 p.c. copper	44·47	15·5
Copper, with 36·7 p.c. zinc	22·27	12·4
Copper, with 25 p.c. zinc	22·08	11·5
Silver, with 5 p.c. platinum *	31·64	11·3
Silver, with 9·8 p.c. platinum *	18·04	7·1
Copper, with 9·7 p.c. tin	12·19	6·6
The gold-silver alloy *	15·03	6·5
Platinum, with 33·4 p.c. iridium	4·54	5·9
Copper, with 10·3 p.c. tin	10·21	5·2
Gold, with 18·1 p.c. silver and 15·4 p.c. copper *	10·6	5·2
Gold, with 15·2 p.c. silver and 26·5 p.c. copper *	12·02	4·8
German silver *	7·80	4·4
Gold, with 5 p.c. iron	2·10	4·3
Gold, with 4·7 p.c. iron	2·37	3·8
Silver, with 25 p.c. palladium	8·52	3·4
Silver, with 33·4 p.c. platinum †	6·70	3·1

It will be observed that I have not yet been able to find an alloy whose conducting power decreases between 0° and 100° less than that of the alloy of silver with 33·4 p.c. platinum; and from results obtained in this direction in conjunction with Dr. Vogt, I am of opinion there will be great difficulty in doing so. We have already tested upwards of 100 alloys, and it is curious how few we have found whose conducting power varies less than that of German silver between 0° and 100°.

Appendix C.—*On the Elementary Relations between Electrical Measurements. By* Professor J. Clerk Maxwell *and* Mr. Fleeming Jenkin.

Part I.—Introductory.

1. *Objects of Treatise.*—The progress and extension of the electric telegraph has made a practical knowledge of electric and magnetic phenomena necessary to a large number of persons who are more or less occupied in the construction and working of the lines, and interesting to many others who are unwilling to be ignorant of the use of the network of wires which surrounds them. The discoveries of Volta and Galvani, of Oersted, and of Faraday are familiar in the mouths of all who talk of science, while the results of those discoveries are the foundation of branches of industry conducted by many who have perhaps never heard of those illustrious names. Between the student's mere knowledge of the history of discovery and the workman's

---

* Proc. Roy. Soc. xii. p. 472 (1863). † *Suprà*, p. 12; and Brit. Assoc. Rep. 1862, p. 137.

practical familiarity with particular operations which can only be communicated to others by direct imitation, we are in want of a set of rules, or rather principles, by which the laws remembered in their abstract form can be applied to estimate the forces required to effect any given practical result.

We may be called on to construct electrical apparatus for a particular purpose. In order to know how many cells are required for the battery, and of what size they should be, we require to know the strength of current required, the electromotive force of the cells, and the resistance of the circuit. If we know the results of previous scientific inquiry, and are acquainted with the method of adapting them to the case before us, we may discover the proper arrangement at once. If we are unable to make any estimate of what is required before constructing the apparatus, we may have to encounter numerous failures which might have been avoided if we had known how to make a proper use of existing data.

All exact knowledge is founded on the comparison of one quantity with another. In many experimental researches conducted by single individuals, the absolute values of those quantities are of no importance; but whenever many persons are to act together, it is necessary that they should have a common understanding of the measures to be employed. The object of the present treatise is to assist in attaining this common understanding as to electrical measurements.

2. *Derivation of Units from fundamental Standards.*—Every distinct kind of quantity requires a standard of its own, and these standards might be chosen quite independently of each other, and in many cases have been so chosen; but it is possible to deduce all standards of quantity from the fundamental standards adopted for length, time, and mass; and it is of great scientific and practical importance to deduce them from these standards in a systematic manner. Thus it is easy to understand what a square foot is when we know what a linear foot is, or to find the number of cubic feet in a room from its length, breadth, and height; because the foot, the square foot, and the cubic foot are parts of the same system of units. But the pint, gallon, &c. form another set of measures of volume which has been formed without reference to the system based on length; and in order to reduce the one set of numbers to the other, we have to multiply by a troublesome fraction, difficult to remember, and therefore a fruitful source of error.

The varieties of weights and measures which formerly prevailed in this country, when different measures were adopted for different kinds of goods, may be taken as an example of the principle of unsystematized standards, while the modern French system, in which every thing is derived from the elementary standards, exhibits the simplicity of the systematic arrangement.

In the opinion of the most practical and the most scientific men, a system in which every unit is derived from the primary units with decimal subdivisions is the best whenever it can be introduced. It is easily learnt; it renders calculation of all kinds simpler; it is more readily accepted by the world at large; and it bears the stamp of the authority, not of this or that legislator or man of science, but of nature.

The phenomena by which electricity is known to us are of a mechanical kind, and therefore they must be measured by mechanical units or standards. Our task is to explain how these units may be derived from the elementary ones; in other words, we shall endeavour to show how all electric phenomena may be measured in terms of time, mass, and space only, referring briefly in each case to a practical method of effecting the observation.

3. *Standard Mechanical Units.*—In this country the standard of length is

one yard, but a foot is the unit popularly adopted. In France it is the ten millionth part of the distance from the pole to the equator, measured along the earth's surface, according to the calculations of Delambre; and this measure is called a metre, and is equal to 3·280899 feet, or 39·37079 inches.

In the original Report the metre was taken as the fundamental unit of length; the gramme, or French standard of weight, is not, however, systematically derived from the metre, being the weight not of a cubic metre, but of a cubic centimetre of water. This consideration has led several Members of the Committee in subsequent writings to adopt the centimetre as the fundamental unit of length. To facilitate comparison with these writings, constants based on the centimetre will be given, besides those for the metre.

The standard unit of time in all civilized countries is deduced from the time of rotation of the earth about its axis. The sidereal day, or the true period of rotation of the earth, can be ascertained with great exactness by the ordinary observations of astronomers; and the mean solar day can be deduced from this by our knowledge of the length of the year. The unit of time adopted in all physical researches is one second of mean solar time.

The standard unit of mass is in this country the avoirdupois pound, as we received it from our ancestors. The grain is one 7000th of a pound. In the French system it is the gramme derived from the unit of length, by the use of water at a standard temperature as a standard of density. The weight of one cubic centimetre of water is a gramme $=15{\cdot}43235$ grains $=\cdot00220462$ lb.

A Table, showing the relative value of the standard and derived units in the British and metrical system is given in § 55.

The unit of force adopted in this treatise is that force which will produce a unit of velocity in a free unit mass, by acting on it during a unit of time. This unit of force is equal to the weight of the unit mass divided by g, where g is the accelerating force of gravity, the value of which, as depending on the place of observation, is given in § 55. In this country it is about 32·2 feet, or 981 centimetres.

A unit of force still very generally used is the weight of the standard mass. This is called the gravitation unit of force, and measurements of force, work, &c. in which it is used are called gravitation measurements. The gravitation unit is equal to the absolute unit multiplied by g.

The unit of work adopted in this treatise is the unit of force, defined as above, acting through the unit of space (*vide* § 55).

4. *Dimensions of Derived Units.*—The name of every quantity consists of two factors or components, and may be written thus, Q[Q].

The first, or numerical factor, Q, is a number, integral or fractional. The second, or denominational factor, [Q], is the name of an individual thing of the same kind as the quantity to be expressed, the magnitude of which is agreed on among men. Thus, in the expression 28 lb., 28 is the numerical part represented by Q, and lb. is the denominational part represented by [Q]. When Q is unity, then the quantity expressed is the unit, 1[Q], or simply [Q]. In the example [Q] is one pound; that is, a piece of platinum preserved in the Exchequer Chambers, and marked "P.S. 1844, 1 lb.," or some copy of the same.

We shall use the symbols [L], [M], and [T] enclosed in square brackets to denote the standards or units of length, mass, and time; and symbols without brackets, such as L, M, T, to denote the number of such units in the quantity to be expressed. Thus if [L] denotes a centimetre and L the number 978, L[L] denotes 978 centimetres. Similarly, if [l] denotes 1 foot and l the number 32·088, l[l] denotes 32·088 feet.

Now these quantities express the same distance measured in two different ways, so that

$$L[L]=l[l];$$

but 1 foot is 30·479 centimetres, or

$$[l]=30{\cdot}479[L].$$

Hence

$$L=30{\cdot}479l;$$

or the numerical factor of the expression of a given quantity varies inversely as the magnitude of the unit employed.

In passing from one system of measurements to another, we first consider the magnitude of the units employed in the two systems and then determine the numerical factors so that the quantity expressed may be the same. Every measurement of which we have to speak involves as factors measurements of time, space, and mass only; but these measurements enter sometimes at one power and sometimes at another. In passing from one set of fundamental units to another, and for other purposes, it is necessary to know at what power each of these fundamental measurements enters into the derived measure.

Thus the value of a force is directly proportional to a length and a mass, but inversely proportional to the square of a time. This is expressed by saying that the *dimensions* of a force are $\left[\frac{LM}{T^2}\right]$; in other words, if we wish to pass from the English to the French system of measurements, the French unit of force will be to the English as $\frac{{\cdot}0328\times 15{\cdot}43}{1}:1$, or as ·506 to 1; because there are ·0328 feet in a centimetre, and 15·43 grains in a gramme. If the metre be adopted as the unit of length, the French unit of force will be to the English as 50·6 to 1. If the minute were chosen as the unit of time, the unit of force would, in either system, be $\frac{1}{3600}$ of that founded on the second as unit.

A Table of the dimensions of every unit adopted in the present treatise is given in § 55.

Part II.—The Measurement of Magnetic Phenomena.

5. *Magnets and Magnetic Poles.*—Certain natural bodies, as the iron ore called loadstone, the earth itself, and pieces of steel after being subjected to certain treatment, are found to possess the following properties, and are called magnets.

If one of these bodies be free to turn in any direction, the presence of another will cause it to set itself in a position which is conveniently described or defined by reference to certain imaginary lines occupying a fixed position in the two bodies, and called their magnetic axes. One object of our magnetic measurements will be to determine the force which one magnet exerts upon another. It is found by experiment that the greatest manifestation of force exerted by one long thin magnet on another occurs very near the ends of the two bars, and that the two ends of any one long thin magnet possess opposite ties. This peculiarity has caused the name of "poles" to be given to he ends of long magnets; and this conception of a magnet, as having wo poles capable of exerting opposite forces joined by a bar exerting no orce, is so much the most familiar that we shall not hesitate to employ t, especially as many of the properties of magnets may be correctly expressed in this way; but it must be borne in mind, in speaking of poles, hat they do not really exist as points or centres of force at the ends of he bar, except in the case of long, infinitely thin, uniformly magnetized ods.

If we mark the poles of any two magnets which possess similar qualities, ve find that the two marked poles repel each other, that two unmarked poles lso repel each other; but that a marked and an unmarked pole attract each ther. The pole which is repelled from the northern regions of the earth is alled the positive pole; the other end the negative pole. The negative pole is enerally marked N by British instrument-makers, and is sometimes called he north pole of the magnet, though it is obviously similar to the earth's outh pole.

The strength of the pole is necessarily defined as proportional to the force it is capable of exerting on any other pole. Hence the force f exerted between two poles of the strengths m and m_1 must be proportional to the product $m\,m_1$. The force f is also found to be inversely proportional to the square of the distance, D, separating the poles, and to depend on no other quantity; hence we have, unless an absurd and useless coefficient be introduced,

$$f=\frac{m\,m_1}{D^2}. \qquad \qquad (1)$$

From which equation it follows that the unit pole will be that which at unit distance repels another similar pole with unit force; f will be an attraction or a repulsion according as the poles are of opposite or the same kinds. The dimensions of the unit magnetic pole are $\left[\frac{L^{\frac{3}{2}}M^{\frac{1}{2}}}{T}\right]$.

6. *Magnetic Field.*—It is clear that the presence of a magnet in some way modifies the surrounding space, since any other magnet brought into that space experiences a peculiar force. The neighbourhood of a magnet is, for convenience, called a magnetic field; and for the same reason the effect produced by a magnet is often spoken of as due to the magnetic field, instead of to the magnet itself. This mode of expression is the more proper, inasmuch as the same or a similar condition of space may be produced by the passage of electrical currents in the neighbourhood, without the presence of a magnet. Since the peculiarity of the magnetic field consists in the presence of a certain force, we may numerically express the properties of the field by measuring the strength and direction of the force, or, as it may be worded, the intensity of the field and the direction of the lines of force.

This direction at any point is the direction in which the force tends to move a free pole; and the intensity, H, of the field is completely defined as proportional to the force, f, with which it acts on a free pole; but this force, f, is also proportional to the strength, m, of the pole introduced into the field, and it depends on no other quantities; hence

$$f=m\mathrm{H}, \qquad \qquad (2)$$

and therefore the field of unit intensity will be that which acts with unit force on the unit pole.

The dimensions of [H] are $\left[\frac{M^{\frac{1}{2}}}{L^{\frac{1}{2}}T}\right]$.

[illegible] negative states, exhibiting [illegible]
[illegible] as unelectrified [illegible]
[illegible] of their union [illegible]
[illegible] properties [illegible]
part of the [illegible]
[illegible]
bodies called [illegible]
[illegible] These [illegible]
the conductor. [illegible]
[illegible] the deficiency [illegible]
[illegible]
[illegible] of the [illegible]
[illegible] discharged [illegible]
rapid succession [illegible]
[illegible] the same [illegible]
[illegible]
[illegible]
[illegible] measured [illegible]
[illegible]
[illegible] are intermittent [illegible]
poles of a battery [illegible]
discharge the [illegible]
with which the [illegible]
[illegible] of the [illegible]
e said to [illegible]
of which is [illegible]
This definition [illegible]

is the current [illegible]
through a wire [illegible]
the [illegible]
[illegible] the [illegible]
quantity is [illegible]
manent current [illegible]
[illegible]
other [illegible]
bouring [illegible]
le from [illegible]
[illegible]
re and V[illegible]
[illegible]
r stationary [illegible]
cannot [illegible]
eats the [illegible]
hemical decomposition [illegible]
k bears a definite [illegible]
in action. The [illegible]
ausing the transfer [illegible]
otive force. This [illegible]
t of a circuit where [illegible]
hus we speak of the [illegible]

electric couple; but the term is also used, independently of the sou power, to express the fact that, however caused, a certain force tending work by setting electricity in motion does, under certain circumst exist between two points of a conductor or between two separate bodies. equal quantities of electricity transferred in a given time do not necessa usually produce equal amounts of work; and the electromotive force bet two points, the proximate cause of the work, is defined as proportional amount of work done between those points when a given quantity of tricity is transferred from one point to another. Thus if, with equal cu in two distinct conductors, the work done in the one is double that d the other in the same time, the electromotive force in the first case i to be double that in the second; but if the work done in two circu found strictly proportional to the two currents, the electromotive force on the two currents is said to be the same. Defined in this way, the el motive force of a voltaic battery is found to be constant so long a materials of which it is formed remain in a similar or constant cond The above definitions, in mathematical language, give $W=ECt$,

$$\text{or}\quad E=\frac{W}{Ct}, \quad . \; . \; . \; . \; . \; , \; . \; . \; . \; . \; .$$

where E is the electromotive force, and W the work done. Thus the tromotive force producing a current in a conductor is equal to the between the work done in the unit of time and the current effectin work. This conception of the relations of work, electromotive force, cu and quantity will be aided by the following analogy:—A quantity of tricity may be compared to a quantity or given mass of water; curre water in pipes in which equal quantities pass each spot in equal times correspond to equal currents of electricity; electromotive force corres to the head of water producing the current. Thus if, with two pipes veying equal currents, the head forcing the water through the first double that forcing it through the second, the work done by the wa flowing through the first pipe would necessarily be twice that done b water in the second pipe; but if twice as much water passed throug first pipe as passes through the second, the work done by water in th pipe would again be doubled. This corresponds exactly with the incre work done by the electrical current when the electromotive force is do and when the quantity is doubled.

Thus, to recapitulate, the quality of a battery or source of electrici virtue of which it tends to do work by the transfer of electricity fro point to another, is called its electromotive force, and this force is mea by measuring the work done during the transfer of a given quanti electricity between these points. The relations between electromotive and work were first fully explained in a paper by Professor W. Thomso the application of the principle of mechanical effect to the measurem electromotive forces, published in the 'Philosophical Magazine' for Dec 1851.

17. *Meaning of the words "Electric Resistance."*—It is found by experi that even when the electromotive force between two points remains con so that the work done by the transfer of a given quantity of elect remains constant, nevertheless, by modifying the material and form o conductor, this transfer may be made to take place in very different ti or, in other words, currents of very different magnitudes are produced very different amounts of work are done, in the unit of time. The qual

he conductor in virtue of which it prevents the performance of more than a ertain amount of work in a given time by a given electromotive force is alled its electrical resistance. The resistance of a conductor is therefore nversely proportional to the work done in it when a given electromotive orce is maintained between its two ends; and hence, by equation (5), it is nversely proportional to the currents which will then be produced in the espective conductors. But it is found by experiment that the current produced in any case in any one conductor is simply proportional to the electromotive force between its ends; hence the ratio $\frac{E}{C}$ will be a constant quantity, o which the resistance as above defined must be proportional, and may with onvenience be made equal; thus

$$R=\frac{E}{C}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

an equation expressing Ohm's law. In order to carry on the parallel with the pipes of water, the resistance overcome by the water must be of such nature that twice the quantity of water will flow through any one pipe when twice the head is applied. This would not be the result of a constant mechanical resistance, but of a resistance which increased in direct proportion to the speed of the current; thus the electrical resistance must not be looked on as analogous to a simple mechanical resistance, but rather to a coefficient by which the speed of the current must be multiplied to obtain the whole mechanical resistance. Thus if the electrical resistance of a conductor be called R, the work, W, is not equal to CRt, but $C \times CR \times t$, or

$$W=C^2Rt\,^*, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where C may be looked on as analogous to a quantity moving at a certain speed, and CR as analogous to the mechanical resistance which it meets with in its progress, and which increases in direct proportion to the quantity conveyed in the unit of time.

18. *Measurement of Electric Currents by their Action on a Magnetic Needle.*—In 1820, Oersted discovered the action of an electric current upon a magnet at a distance, and one method of measurement may be based on this action. Let us suppose the current to be in the circumference of a vertical circle, so that in the upper part it runs from left to right. Then a magnet suspended in the centre of the circle will turn with the end which points to the north away from the observer. This may be taken as the simplest case, as every part of the circuit is at the same distance from the magnet, and tends to turn it the same way. The force is proportional to the moment of the magnet, to the strength of the current as defined by § 15, to its length, and inversely to the square of its distance from the magnet.

Let the moment of the magnet be ml, the strength of the current C, the radius of the circle k, the number of times the current passes round the circle n, the angle between the axes of the magnet and the plane of the circle θ, and the moment tending to turn the magnet G, then

$$G=mlC\,.\,2\pi nk\,\frac{1}{k^2}\cos\theta, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

---

* By equation (5) we have $W=CEt$; but by equation (6) $R=\frac{E}{C}$; hence $W=C^2Rt$.—Q.E.D.

which will be unity if ml, C, k, and the length of the circuit be unity, and if $\theta = 0°$.

The unit of current founded on this relation, and called the electro-magnetic unit, is therefore that current of which the unit of length placed along the circumference of a circle of unit radius produces a unit of magnetic force at the centre.

The usual way of measuring C, the strength of a current, is by making it describe a circle about a magnet, the plane of the circle being vertical and magnetic north and south. Thus, if H be the intensity of the horizontal component of terrestrial magnetism, and G the moment of this on the magnet, $G = mlH \sin \theta$, whence the strength of the current—

$$C = \frac{k}{2\pi n} H \tan \theta, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

where k is the radius of the circle, n the number of turns, H the intensity of the horizontal part of the earth's magnetic force as determined by the usual method, and θ the angle of deviation of the magnet suspended in the centre of the circle. As the strength of the current is proportional to the tangent of the angle θ, an instrument constructed on this plan is called a tangent galvanometer. The instrument called a sine galvanomter may also be used, provided the coil is circular. The equation is similar to that just given, substituting $\sin \theta$ for $\tan \theta$.

To find the dimensions of [C], the unit electric current, we must consider that what we observe is the force acting between a magnetic pole, m, and a current of given length, L, at a given distance, L_1, and that this force $= \frac{mCL}{L_1^2}$. Hence the dimensions of [C], the unit electric current, are $\left[\frac{L^{\frac{1}{2}} M^{\frac{1}{2}}}{T}\right]$.

19. *Measurement of Electric Currents by their mutual action on one another.*—Hitherto we have spoken of the measurement of currents as dependent on their action upon magnets; but this measurement in the same units can as simply be founded on their mutual action upon one another. Ampère has investigated the laws of mechanical action between conductors carrying currents. He has shown that the action of a small closed circuit at a distance is the same as that of a small magnet, provided the axis of the magnet be placed normal to the plane of the circuit, and the moment of the magnet be equal to the product of the current into the area of the circuit which it traverses.

Thus, let two small circuits, having areas A and A_1, be placed at a great distance, D, from each other in such a way that their planes are at right angles to each other, and that the line D is in the intersection of the planes. Now let currents, C and C_1, circulate in these conductors; a force will act between them tending to make their planes parallel, and the direction of the currents opposite. The moment of this couple will be

$$G = \frac{AC \times A_1C_1}{D^3}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Hence the unit electric current conducted round two circuits of unit area in vertical planes at right angles to each other, one circuit being at a great distance, D, vertically above the other, will cause a couple to act between the circuits of a magnitude $\frac{1}{D^3}$. The definition of the unit current (identical with the unit founded on the relations given in § 18) might be founded on this action quite independently of the idea of magnetism.

20. *Weber's Electro-dynamometer.*—The measurement described in the last paragraph is only accurate when D is very great, and therefore the moment to be measured very small. Hence it is better to make the experimental measurements in another form. For this purpose, let a length (l) of wire be made into a circular coil of radius k; let a length (l_1) of wire be made into a coil of very much smaller radius, k_1. Let the second coil be hung in the centre of the first, the planes being vertical and at the angle θ. Then, if a current C traverses both coils, the moment of the force tending to bring them parallel will be

$$G=\tfrac{1}{2}C^2\frac{ll_1k_1}{k^2}\sin\theta. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

This force may be measured in mechanical units by the angle through which it turns the suspended coil, the forces called into play by the mechanical arrangements of suspension being known from the construction of the instrument. Weber used a bifilar suspension, by which the weight of the smaller coil was used to resist the moment produced by the action of the currents.

21. *Comparison of the Electro-magnetic and Electro-chemical action of Currents.*—Currents of electricity, when passed through certain compound substances, decompose them; and it is found that, with any given substance, the weight of the body decomposed in a given time is proportional to the strength of the current as already defined with reference to its electro-magnetic effect. The voltameter is an apparatus of this kind, in which water is the substance decomposed. Special precautions have to be taken, in carrying this method of measurement into effect, to prevent variations in the resistance of the circuit, and consequently in the strength of the current. This subject is more fully treated in Part V. §§ 53, 54.

22. *Magnetic Field near a Current.*—Since a current exerts a force on the pole of a magnet in its neighbourhood, it may be said to produce a magnetic field (§ 6), and, by exploring this field with a magnet, we may draw lines of force and equipotential surfaces of the same nature as those already described for magnetic fields caused by the presence of magnets.

When the current is a straight line of indefinite length, like a telegraph-wire, a magnetic pole in its neighbourhood is urged by a force tending to turn it round the wire, so that this force is at any point perpendicular to the plane passing through this point and the axis of the current.

The equipotential surfaces are therefore a series of planes passing through the axis of the current, and inclined at equal angles to each other. The number of these planes is $4\pi C$, where C is the strength of the current.

The lines of magnetic force are circles having their centres in the axis of the current, and their planes perpendicular to it. The intensity of the magnetic force at a distance, k, from the current is the reciprocal of the distance between two equipotential surfaces, which shows the force to be $\frac{2C}{k}$.

The work done on a unit magnetic pole in going completely round the current is $4\pi C$, whatever the path which the pole describes.

23. *Mechanical Action of a Magnetic Field on a closed Conductor conveying a Current.*—When there is mechanical action between a conductor carrying a

current and a magnet, the force acting on the conductor must be equal and opposite to that acting on the magnet. Every part of the conductor is therefore acted on by a force perpendicular to the plane passing through its own direction and the lines of magnetic force due to the magnet, and equal to the product of the length of the conductor into the strength of the current, the intensity of the magnetic field, and the sine of the angle between the lines of force and the direction of the current. This may be more concisely expressed by saying, that if a conductor carrying a current is moved in a magnetic field, the work done on the conductor by the electro-magnetic forces is equal to the product of the strength of the current into the *number* of lines of force which it cuts during its motion.

Hence we arrive at the following general law, for determining the mechanical action on a closed conductor carrying a current and placed in a magnetic field:—

Draw the lines of magnetic force. Count the number which pass through the area enclosed by the circuit of the conductor, then any motion which increases this number will be aided by the electro-magnetic forces; so that the work done during the motion will be the product of the strength of the current and the number of additional lines of force.

For instance, let the lines of force be due to a single magnetic pole of strength m. These are $4\pi m$ in number, and are in this case straight lines radiating equally in all directions from the pole. Describe a sphere about the pole, and project the circuit on its surface by lines drawn to the pole. The surface of the area so described on the sphere will measure the solid angle subtended by the circuit at the pole. Let this solid angle $=\omega$, then the number of lines passing through the closed surface will be $m\omega$; and if C be the strength of the current, the amount of work done by bringing the magnet and circuit from an infinite distance apart to their present position will be $Cm\omega$. This shows that the magnetic potential of a closed circuit carrying a unit current with respect to a unit magnetic pole placed at any point is equal to the solid angle which the circuit subtends at that point.

By considering at what points the circuit subtends equal solid angles, we may form an idea of the surfaces of equal potential. They form a series of sheets, all intersecting each other in the circuit itself, which forms the boundary of every sheet. The number of sheets is $4\pi C$, where C is the strength of the current. The lines of magnetic force intersect these surfaces at right angles, and therefore form a system of rings encircling every point of the circuit. When we have studied the general form of the lines of force, we can form some idea of the electro-magnetic action of that current, after which the difficulties of numerical calculation arise entirely from the imperfection of our mathematical skill.

24. *General Law of the Mechanical Action between Electric Currents and other Electric Currents or Magnets.*—Draw the lines of magnetic force due to all the currents, magnets, &c. in the field, supposing the strength of each current or magnet to be reduced from its actual value to unity. Call the number of lines of force due to a circuit or magnet, which pass through another circuit, the potential coefficient between the one and the other. This number is to be reckoned positive when the lines of force pass through the circuit in the same direction as those due to a current in that circuit, and negative when they pass in the opposite direction.

If we now ascertain the change of the potential coefficient due to any displacement, this increment multiplied by the product of the strengths of the rents or magnets will be the amount of work done by the mutual action of ity be slowly conveyed as a static charge on an insulated ball, the e spent or gained in accelerating or retarding the ball; if the elec onveyed rapidly through a conductor of small resistance, or more ugh a conductor of great resistance, the work may be spent in heat ductor, or it may electrolyze a solution, or be thermo electrically cally used; but in all cases the change effected, measured as equi ork done, will be the same, and equal to EQ. Hence the electro e from the point A to the point B is unity, if a unit of mechanical ined in the transfer of a unit of electricity from A to B. The inition is due to Professor W. Thomson.

ct measurement of electromotive force may be made by the mea n any given case of the work done by the transfer of a given electricity. The ratio between the numbers measuring the work he quantity transferred would measure the electromotive force rement has been made by Dr. Joule and Professor Thomson, by g the heat developed in a wire by a given current [illegible]

irect Measurements of Electromotive Force.- The direct method of nt is in most cases inconvenient, and in many impossible [illegible] ethods are numerous and easily applied. The relation [illegible] the resistance, R, and the electromotive force, E, [illegible] equation 6), will determine the electromotive force [illegible] R and C are known. A second indirect method [illegible] nt of the statical force with which two bodies [illegible] given electromotive force is maintained between them [illegible] y treated in Part IV. (43). The phenomenon on [illegible] n easy comparison between various electromotive forces [illegible] This method is applicable even to those cases [illegible] e to be measured is incapable of maintaining [illegible] mical electrolysis and electro-magnetic [illegible] ethods of estimating electromotive force [illegible]

surement of Electric Resistance.- [illegible] of a conductor is that property [illegible] work performed by a given electromotive [illegible]

e shown that it may be measured [illegible]

e between two ends of a conductor [illegible] nit resistance is therefore [illegible] es the unit current [illegible] time. If [illegible] e, or even [illegible] he resist[illegible] [illegible] n Ampere [illegible] rrents and [illegible] [illegible] method [illegible] ances [illegible] electro[illegible] apacity and [illegible] where, as before, k = the radius of the coil, and n = the number of turns made by the wire round the coil.

The quantity in a given charge which can be continually reproduced under fixed conditions may be measured by allowing a succession of discharges to pass at regular and very short intervals through a galvanometer, so as to produce a permanent deflection. The value of a current producing this deflection can be ascertained; and the quotient of this value by the number of discharges taking place in a 'second' gives the value of each charge in electro-magnetic measure.

To find the dimensions of [Q], we simply observe that the unit of electricity is that which is transferred by the unit current in the unit of time. Multiplying the dimensions of [C] by [T], we find the dimensions of [Q] are $[L^{\frac{1}{2}}\,M^{\frac{1}{2}}]$.

26. *Electric Capacity of a Conductor.*—It is found by experiment that, other circumstances remaining the same, the charge on an insulated conductor is simply proportional to the electromotive force between it and the surrounding conductors, or, in other words, to the difference of potentials (47). The charge that would be produced by the unit electromotive force is said to measure the electric capacity of a conductor. Thus, generally, the capacity of a conductor $S=\frac{Q}{E}$, where Q is the whole quantity in the charge produced by the electromotive force E. When the electromotive force producing the charge is capable of maintaining a current, the capacity of the conductor may be obtained without a knowledge of the value either of Q or E, provided we have the means of measuring the resistance of a circuit in electro-magnetic measure. For let R_1 be the resistance of a circuit, in which the given electromotive force E will produce the unit deflection on a tangent galvanometer, then, from equations (6) and (12), we have

$$S=2\frac{t\sin\frac{1}{2}i}{\pi R_1}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where t and i retain the same signification as in equation (13) (§ 25).

27. *Direct Measurement of Electromotive Force.*—The meaning of the words "electromotive force" has already been explained (§ 16); this force tends to do work by means of a current or transfer of electricity, and may therefore be said to produce and maintain the current. In any given combination in which electric currents flow, the immediate source of the power by which the work is done is said to produce the electromotive force. The sources of power producing electromotive force are various. Of these, chemical action in the voltaic battery, unequal distribution of temperature in circuits of different conductors, the friction of different substances, magneto-electric induction, and simple electric induction are the most familiar. An electromotive force may exist between two points of a conductor, or between two points of an insulator, or between an insulator and a conductor,—in fine, between any points whatever. This electromotive force may be capable of maintaining a current for a long time, as in a voltaic battery, or may instantly cease after producing a current of no sensible duration, as when two points of the atmosphere at different potentials (§ 47) are joined by a conductor; but in every case in which a constant electromotive force E is maintained between any two points, however situated, the work spent or gained in transferring a quantity, Q, of electricity from one of those points to the other will be constant; nor will this work be affected by the manner or method of the transfer. If

the electricity be slowly conveyed as a static charge on an insulated ball, the work will be spent or gained in accelerating or retarding the ball; if the electricity be conveyed rapidly through a conductor of small resistance, or more slowly through a conductor of great resistance, the work may be spent in heating the conductor, or it may electrolyze a solution, or be thermo-electrically or mechanically used; but in all cases the change effected, measured as equivalent to work done, will be the same, and equal to EQ. Hence the electromotive force from the point A to the point B is unity, if a unit of mechanical work is gained in the transfer of a unit of electricity from A to B. This general definition is due to Professor W. Thomson.

The direct measurement of electromotive force may be made by the measurement in any given case of the work done by the transfer of a given quantity of electricity. The ratio between the numbers measuring the work done and the quantity transferred would measure the electromotive force. This measurement has been made by Dr. Joule and Professor Thomson, by determining the heat developed in a wire by a given current measured as in § 18*.

28. *Indirect Measurements of Electromotive Force.*—The direct method of measurement is in most cases inconvenient, and in many impossible; but the indirect methods are numerous and easily applied. The relation between the current, C, the resistance, R, and the electromotive force, E, expressed by Ohm's law (equation 6), will determine the electromotive force of a battery whenever R and C are known. A second indirect method depends on the measurement of the statical force with which two bodies attract one another when the given electromotive force is maintained between them. This method is fully treated in Part IV. (43). The phenomenon on which it is based admits of an easy comparison between various electromotive forces by electrometers. This method is applicable even to those cases in which the electromotive force to be measured is incapable of maintaining a current. The laws of chemical electrolysis and electro-magnetic induction afford two other indirect methods of estimating electromotive force in special cases (54 and 31).

29. *Measurement of Electric Resistance.*—We have already stated that the resistance of a conductor is that property in virtue of which it limits the amount of work performed by a given electromotive force in a given time, and we have shown that it may be measured by the ratio $\frac{E}{C}$ of the electromotive force between two ends of a conductor to the current maintained by it. The unit resistance is therefore that in which the unit electromotive force produces the unit current, and therefore performs the unit of work in the unit of time. If in any circuit we can measure the current and electromotive force, or even the ratio of these magnitudes, we should, *ipso facto*, have measured the resistance of the circuit. The methods by which this ratio has been measured, founded on the laws of electro-magnetic induction, are fully described in Appendix D. Other methods may be founded on the measurement of currents and electromotive forces described in 18, 19, 20, 27, and 28. Lastly, a method founded on the gradual loss of charge through very great resistances will be found in Part IV. (45). The equation (25) there given for electrostatic measure is applicable to electro-magnetic measure when the capacity and difference of potentials are expressed in electro-magnetic units.

---

* Phil. Mag. vol. ii. 4th ser. 1851, p. 551.

30. *Electric Resistance in Electro-magnetic Units is measured by an Absolute Velocity.*—The dimensions of [R] are found, by comparing those of [E] and [C], to be $\left[\frac{L}{T}\right]$, or those of a simple velocity. This velocity, as was pointed out by Weber, is an absolute velocity in nature quite independent of the magnitude of the fundamental units in which it is expressed. The following illustration, due to Professor Thomson, will show how a velocity may express a resistance, and also how that expression may be independent of the magnitude of the units of time and space.

Let a wire of any material be bent into an arc of $57\frac{1}{4}°$ with any radius, k. Let this arc be placed in the magnetic meridian of any magnetic field, with a magnet of any strength freely suspended in the centre of the arc. Let two vertical wires or rails, separated by a distance equal to k, be attached by a wire to the ends of the arc; and let a cross piece slide along these rails inducing a current in the arc. Then it may be shown that the speed required to produce a deflection of 45° on the magnet will measure the resistance of the circuit, which is assumed to be constant. This speed will be the same whatever be the value of k, or the intensity of the magnetic field, or the moment of the magnet. In this form the experiment could not be easily carried out; but if a length, l, of wire be taken and rolled into a circular coil at the radius k, and the distance between the vertical rails be taken equal to $\frac{k^2}{l}$, then if the resistance of the circuit be the same as in the previous case, the deflection of 45° will be produced by the same velocity in the cross piece, measuring that resistance; or, generally, if the distance between the rails be $p\frac{k^2}{l}$, then p times the velocity required to produce the unit deflection (45°) will measure the resistance. The truth of this proposition can easily be established when the laws of magneto-electric induction have been understood (31).

31. *Magneto-electric Induction.*—Let a conducting circuit be placed in a magnetic field. Let C be the intensity of any current in that circuit; E the magnitude of the electromotive force acting in the circuit. Let the circuit be so moved that the number of lines of magnetic force (11) passing through the area which it encloses is increased by N in the time t, then (23) the electro-magnetic forces will contribute towards the motion an amount of work measured by CN. Now Q, the quantity of electricity which passes, is equal to Ct; so that the work done on the current is EQ or CEt. By the principle of conservation of energy, the work done by the electro-magnetic forces must be at the expense of that done by the electromotive forces, or

$$CN + CEt = 0\,;$$

or dividing by Ct, we find that

$$E = -\frac{N}{t}\,; \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (15)$$

or, in other words, if the number of lines of force passing through the area enclosed by a circuit be increased, an electromotive force in the negative direction will act in the circuit measured by the number of lines of force added per second.

If R be the resistance of the circuit, we have, by Ohm's law (equation 6), $E = CR$; and therefore

$$N = -Et = -RCt = -RQ\,; \quad . \; . \; . \; . \; . \; . \quad (16)$$

or, in other words, if the number of lines of magnetic force passing through the area enclosed by the circuit is altered, a current will be produced in the circuit in the direction opposite to that of a current which would have produced lines of force in the direction of those added, and the quantity of electricity which passes multiplied by the resistance of the circuit measures the number of additional lines passing through the area enclosed by the circuit.

The facts of magneto-electric induction were discovered by Faraday, and described by him in the First Series of his "Experimental Researches in Electricity," read to the Royal Society, 24th November, 1831.

He has shown* the relation between the induced current and the lines of force cut by the circuit treated as a surface or area, and he has also described the state of a conductor in a field of force as a state the change of which is a cause of currents. He calls it the electrotonic state; and, as we have just seen, the electrotonic state may be *measured* by the number of lines of force which pass through the circuit at any time.

The measure of electromotive force used by W. Weber, and derived by him (independently of the principle of conservation of energy) from the motion of a conductor in a magnetic field, is the same as that at which we have arrived; for, from equation (15), we find that the unit electromotive force will be produced by motion in a magnetic field when one line of force is added (or subtracted) per unit of time, and this will occur when in a field of unit intensity a straight bar of unit length, forming part of a circuit otherwise at rest, is moved with unit velocity perpendicularly to the lines of force and to its own direction.

To W. Weber, whose numerical determinations of electrical magnitudes are the starting-point of exact science in electricity, we owe this, the first definition of the unit of electromotive force; but to Professor Helmholtz† and to Professor W. Thomson‡, working independently of each other, we owe the proof of the necessary existence of magneto-electric induction and the determination of electromotive force on strictly mechanical principles.

32. *On Material Standards for the Measurement of Electric Magnitudes.*—The comparison between two different electrical magnitudes of the same nature, *e. g.* between two currents or between two resistances, is in all cases much simpler than the direct measurements of these magnitudes in terms of time, mass, and space, as described in the foregoing pages. Much labour is, therefore, saved by the use of standards of each magnitude; and the construction and diffusion of those standards form part of the duties of the Committee.

Electric currents are most simply compared by "electro-dynamometers" (20) —instruments which, unlike galvanometers, are practically independent of the intensity of the earth's magnetism. When an instrument of this kind has been constructed, with which the values of the currents corresponding to each deflection has been measured (19, 20), other instruments may easily be so compared with this standard, that the relative value of the deflections produced by equal currents on the standard and the copies shall be known. Hence the absolute value of the current indicated by each deflection of each copy will be known in absolute measure. In other words, in order to obtain the electro-magnetic measure of a current in the system described, each observer in possession of an electro-dynamometer which has been compared with the standard instrument will simply multiply by a constant number the deflection produced by the current on his instrument (or the tangent or sine of the deflection, according to the particular construction of the instrument).

---

* Experimental Researches, 3082, &c.

† Paper read before the Physical Society of Berlin, 1847 (*vide* Taylor's Scientific Memoirs, part ii. Feb. 1853, p. 114).

‡ Transactions of the British Association, 1848; Phil. Mag., Dec. 1851.

Electric quantities may be compared by the swing of the needle of a galvanometer of any kind. They may be measured by any one in possession of a standard electro-dynamometer, or resistance-coil, since the observer will then be in a position directly to determine C, in equation (12), or R, in equation (14).

Capacities may be compared by the methods described (26); and a Leyden jar or condenser (41) of unit capacity, and copies derived from it, may be prepared and distributed. The owner of such a condenser, if he can measure electromotive force, can determine the quantity in his condenser.

The material standard for *electromotive force* derived from electro-magnetic phenomena would naturally be a conductor of known shape and dimensions, moving in a known manner in a known magnetic field. Such a standard as this would be far too complex to be practically useful: fortunately a very simple and practical standard or gauge of electromotive force can be based on its statical effects, and will be described in treating of those effects (Part IV. 43). A practical standard for approximate measurements might be formed by a voltaic couple, the constituent parts of which were in a standard condition. It is probable that the Daniell's cell may form a practical standard of reference in this way, when its value in electro-magnetic measure is known. This value (centimetre-gramme second) lies between 9×10^7 and 11×10^7 (or 9×10^4 and 11×10^4 metre-gramme second). [*Note*, 1872.—Mr. Latimer Clark's cell equal to $1{\cdot}457 \times 10^8$ centimetre-gramme second series, or $1{\cdot}457 \times 10^5$ metre-gramme second series, is a better standard of E.M.F. This cell is composed of pure mercury as the negative element, the mercury being covered by a paste made by boiling mercurous sulphate in a thoroughly saturated solution of zinc sulphate, the positive element consisting of pure zinc resting on the paste. This element must not be used to produce a current, but forms an excellent standard of E.M.F., when compared with other cells, by any method which does not involve the passage of a current through the cell (*vide* 'Proc. Roy. Soc.' no. 136, 1872).]

Resistances are compared by comparing currents produced in the several conductors by one and the same electromotive force. The unit resistance, determined as in Appendix D, will be represented by a material conductor; simple coils of insulated wire compared with this standard, and issued by the Committee, will allow any observer to measure any resistance in electro-magnetic measure.

Part IV.—MEASUREMENT OF ELECTRIC PHENOMENA BY STATICAL EFFECTS.

33. *Electrostatic Measure of Electric Quantity.*—By the application of a sufficient electromotive force between two parts of a conductor which does not form a circuit, it is possible to communicate to either part a *charge* of electricity which may be maintained in both parts, if properly insulated (14). With the ordinary electromotive forces due to induction or chemical action, and the ordinary size of insulated conductors, the charge of electricity in electro-magnetic measure is exceedingly small; but when the capacity of the conductor is great, as in the case of long submarine cables, the charge may be considerable. By making use of the electromotive force produced by the friction of unlike substances, the charge or electrification even of small bodies may be made to produce visible effects. The electricity in a charge is

not essentially in motion, as is the case with the electricity in a current. In other words, a charge may be permanently maintained without the performance of work. Electricity in this condition is therefore frequently spoken of as statical electricity, and its effects, to distinguish them from those produced by currents, may be called statical effects. The peculiar properties of electrically charged bodies are these:—

1. When one body is charged positively (14), some other body or bodies must be charged negatively to the same extent.

2. Two bodies repel one another when both are charged positively, or both negatively, and attract when oppositely charged.

3. These forces are inversely proportional to the square of the distance of the attracting or repelling charges of electricity.

4. If a body electrified in any given invariable manner be placed in the neighbourhood of any number of electrified bodies, it will experience a force which is the resultant of the forces that would be separately exerted upon it by the different bodies if they were placed in succession in the positions which they actually occupy, without any alteration in their electrical conditions.

From these propositions it follows that, at a given distance, the force, f, with which two small electrified bodies repel one another is proportional to the product of the charges, q and q_1, upon them. But when the distance varies, this force, f, is inversely proportional to the square of the distance, d, between them; hence

$$f=\frac{qq_1}{d^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

When q and q_1 are of dissimilar signs, f becomes negative, *i. e.* there is an attraction, and not a repulsion. This equation is incompatible with the electro-magnetic definitions given in Part III., and, if it be allowed to be fundamental, gives a new definition of the unit quantity of electricity, as that quantity which, if placed at unit distance from another equal quantity of the same kind, repels it with unit force.

34. *Electrostatic System of Units.*—This new measurement of quantity forms the foundation of a distinct system or series of units, which may be called the electrostatic units, and measurements in these units will in these pages be designated by the use of small letters; thus, as Q, C, &c. signify the number of electrostatic units in the same quantities, currents, &c. in *electro-magnetic* measure, so q, c, e, and r, &c. will represent the *electrostatic* measure of quantity, current, electromotive force, resistance, &c.

The relations between current and quantity, between work, current, and electromotive force, and between electromotive force, current, and resistance, remain unchanged by the change from the electro-magnetic to the electrostatic system.

35. *Ratio between Electrostatic and Electro-magnetic Measures of Quantity.*—Since the expression forming the second member of equation (17) represents a force the dimensions of which are $\left[\frac{\mathrm{LM}}{\mathrm{T}^2}\right]$, the dimensions of $[q]$ are $\left[\frac{\mathrm{L}^{\frac{3}{2}}\mathrm{M}^{\frac{1}{2}}}{\mathrm{T}}\right]$. The dimensions of the unit of electricity, [Q], in the electro-magnetic system are $[\mathrm{L}^{\frac{1}{2}}\mathrm{M}^{\frac{1}{2}}]$ (25). Hence, since in passing from the one system to the other we must employ the ratio $\frac{q}{\mathrm{Q}}$, this ratio will be of the dimension $\left[\frac{\mathrm{L}}{\mathrm{T}}\right]$; that is to

say, it is of the nature of a velocity. In the present treatise this velocity will be designated by the letter v.

The first estimate of the relation between quantity of electricity measured statically and the quantity transferred by a current in a given time was made by Faraday*. A careful experimental investigation by MM. Weber and Kohlrausch† not only confirms the conclusion that the two kinds of measurements are consistent, but shows that the velocity v is 310,740,000 metres per second—a velocity not differing from the estimated velocity of light more than the different determinations of the latter quantity differ from each other. v must always be a constant real velocity in nature, and should be measured in terms of the system of fundamental units adopted in electrical measurements (3 and 55). A redetermination of v (46) will form part of the present Committee's business in 1863–64. It will be seen that, by definition, the quantity transmitted by an electro-magnetic unit current in the unit time is equal to v electrostatic units of quantity. In the centimetre-gramme second series the value of v will clearly be 100 times as great as that given above.

36. *Electrostatic Measure of Currents.*—In any coherent system, a current is measured by the quantity of electricity which passes in the unit of time (15); if both current and quantity are measured in electrostatic units, then

$$c=\frac{q}{t}. \qquad (18)$$

The dimensions of $[c]$ are therefore $\left[\frac{L^{\frac{3}{2}}M^{\frac{1}{2}}}{T^2}\right]$; and in order to reduce a current from electro-magnetic to electrostatic measure, we must multiply C by v, or

$$c=vC. \qquad (19)$$

37. *Electrostatic Measure of Electromotive Force.*—The statical measure of an electromotive force is the work which would be done by electrical forces during the passage of a unit of electricity from one point to another. The only difference between this definition and the electro-magnetic definition (16 and 27) consists in the change of the unit of electricity from the electromagnetic to the electrostatic.

Hence if q units of electricity are transferred from one place to another, the electromotive force between those places being e, the work done during the transfer will be qe; but we found (27) that if E and Q be the electromagnetic measures of the same quantities, the work done would be expressed by QE; hence

$$qe=QE;$$

but (35) $$q=vQ,$$

therefore $$e=\frac{E}{v}. \qquad (20)$$

Thus, to reduce electromotive force from electro-magnetic to electrostatic measure, we must divide by v.

The dimensions of e are $\frac{L^{\frac{1}{2}}M^{\frac{1}{2}}}{T}$.

38. *Electrostatic Measure of Resistance.*—If an electromotive force, e, act

---

* Experimental Researches, series iii. § 361, &c.

† Abhandlungen der König. Sächsischen Ges. Bd. iii. (1857) p. 260; or, Poggendorff's Annalen, Bd. xcix. p. 10 (Aug. 1856).

n a conductor whose resistance in electrostatic measure is r, and produce a current, c, then by Ohm's law

$$r=\frac{e}{c}. \qquad (21)$$

Substituting for e and c their equivalents in electro-magnetic measure (equations 19 and 20), we have

$$r=\frac{1}{v^2}\frac{\mathrm{E}}{\mathrm{C}};$$

but (eq. 7),

$$\mathrm{R}=\frac{\mathrm{E}}{\mathrm{C}},$$

and therefore

$$r=\frac{1}{v^2}\mathrm{R}. \qquad (22)$$

Hence, to reduce a resistance measured in electro-magnetic units to its electrostatic value, we must divide by v^2.

The dimensions of $[r]$ are $\left[\frac{\mathrm{T}}{\mathrm{L}}\right]$, or the reciprocal of a velocity.

39. *Electric Resistance in Electrostatic Units is measured by the Reciprocal of an Absolute Velocity.*—We have seen from the last paragraph that the dimensions of r establish this proposition; but the following independent definition, due to Professor W. Thomson, assists the mind in receiving this conception as a necessary natural truth. Conceive a sphere of radius k, charged with a given quantity of electricity, Q. The potential of the sphere, when at a distance from all other bodies, will be $\frac{\mathrm{Q}}{k}$ (40, 41, and 47). Let it now be discharged through a certain resistance, r. Then if the sphere could collapse with such a velocity that its potential should remain constant, or, in other words, that the ratio of the quantity on the sphere to its radius should remain constant, during the discharge, then the time occupied by its radius in shrinking the unit of length would measure the resistance of the discharging conductor in electrostatic measure, or the velocity with which its radius diminished would measure the conducting power (50) of the discharging conductor. Thus the conducting power of a few yards of silk in dry weather might be an inch per second, in damp weather a yard per second. The resistance of 1000 miles of pure copper wire, $\frac{1}{16}$ inch in diameter, would be about 0·00000141 of a second per metre, or its conducting power one metre per 0·00000141 of a second, or 709220 metres per second.

40. *Electrostatic Measure of the Capacity of a Conductor.*—The electrostatic capacity of a conductor is equal to the quantity of electricity with which it can be charged by the unit electromotive force. This definition is identical with that given of capacity measured in electro-magnetic units (26). Let s be the capacity of a conductor, q the electricity in it, and e the electromotive force charging it; then

$$q=se. \qquad (23)$$

From this equation we can see that the dimension of the quantity s is a length only. It will also be seen that

$$s=v^2\mathrm{S}, \qquad (24)$$

where S is the electro-magnetic measure of the capacity of the conductor with the electrostatic capacity, s.

The capacity of a spherical conductor in an open space is, in electrostatic measure, equal to the radius of the sphere—a fact demonstrable from the fundamental equation (17).

Experimentally to determine s, the capacity of the conductor in electrostatic measure, charge it with a quantity, q, of electricity, and measure in any unit its potential (47), e. Then bring it into electrical connexion with another conductor whose capacity, s_1, is known. Measure the potential, e_1, of s and s_1 after the charge is divided between them; then

$$q=se=(s+s_1)e_1,$$

and hence

$$s=\frac{e_1}{e-e_1}s_1. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

In this measurement we do not require to know e and e_1 in absolute measure, since the ratio of these two quantities only is required. We must, however, know the value of s_1; and hence we must begin either with a spherical conductor in a large open space, whose capacity is measured by its radius, or with some other form of absolute condenser alluded to in the following paragraph.

41. *Absolute Condenser. Practical Measurement of Quantity.*—As soon as the electromotive force of a source of electricity is known in electrostatic measure, the quantity which it will produce in the form of charge on simple figures is known by the laws of electrical distribution experimentally proved by Coulomb. Such simple figures may be termed ***absolute condensers.*** A sphere in an open space is such a condenser, and its capacity is numerically equal to its radius. A more convenient form is a sphere of radius x, suspended in the centre of a hollow sphere, radius y, the latter being in communication with the earth. The capacity, s, of the internal sphere is then, by calculation,

$$s=\frac{xy}{y-x}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

By a series of condensers of increasing capacity, we may measure the capacity of any condenser, however large. The comparison is made by the method described above (40). Thus, the practical method of measuring quantity in electrostatic measure is first to determine the capacity of the conductor containing the charge, and then to multiply that capacity by the electromotive force producing the charge (43).

42. *Practical Measurement of Currents.*—The electrostatic value of currents can be obtained from equation (21), when e and r are known, or from equation (19), when v and C are known, or by comparison with a succession of discharges of known quantities from an absolute condenser.

43. *Practical Measurement of Electromotive Force.*—The relations expressed by eq. (17) and (23) show that in any given circumstances the force exerted between two bodies due to the effects of statical electricity will be proportional to the electromotive force or difference of potential (47) between them. This fact allows us to construct gauges of electromotive force, or instruments so arranged that a given electromotive force between two parts of the apparatus brings an index into a sighted position. In order that the gauge should serve to *measure* the electromotive force absolutely, it is necessary that two things should be known: first, the distribution of the electricity over the two attracting or repelling masses (or, in other words, the capacity of each part); secondly, the absolute force exerted between them. For simple forms, the distribution capacity of each part can be calculated from the fundamental principles

(33); the force actually exerted can be weighed by a balance. By these means Professor W. Thomson * determined the electromotive force of a Daniell's cell to be 0·0021 in British electrostatic units, or 0·0002951 in metrical units, or 0·002951 in centimetrical units. This proposition is equivalent to saying that two balls of a metre radius, at a distance *d* apart, measured in metres, in a large open space, and in connexion with the opposite poles of a Daniell's cell, would attract one another with a force equal

$$\text{to } \frac{0·0002951\times 0·0002951}{d^2} \text{ absolute metrical units,}$$

$$\text{or } \frac{0·000000008876}{d^2} \text{ gramme weight.}$$

An apparatus by which such a measurement as the foregoing can be carried out is called an absolute electrometer. It will be observed that, although the definition of electromotive force is founded on the idea of work, its practical measurement is effected by observing a force, inasmuch as when this force exerted between two conductors of simple shape is known, the work which the passage of a unit of electricity between them would perform may be calculated by known laws.

44. *Comparison of Electromotive Forces by their Statical Effects.*—This comparison is simpler than the absolute measurement, inasmuch as it is not necessary, in comparing two forces, to know the absolute values of either. Instruments by which the comparison can be made are called electrometers. Their arrangement is of necessity such that the force exerted between two given parts of the instrument shall be proportional to the difference of potential between them †. This force may be variable and measured by the torsion of a wire, as in Thomson's reflecting electrometer, or it may be constant, and the electromotive forces producing it may be compared by measuring the distance between the two electrified bodies at which these attract each other with that constant force. The latter arrangement is adopted in Professor Thomson's portable electrometer, first exhibited at the present meeting of the Association. The indications of a gauge or electrometer not in itself absolute may be reduced to absolute measurement by multiplication into a constant coefficient.

45. *Practical Measurement of Electric Resistance.*—The electrostatic resistance of a conductor of great resistance (such as gutta percha or india rubber) might be directly obtained in the following manner:—Let a body of known capacity, *s* (40), be charged to a given potential, P (47), and let it be gradually discharged through the conductor of great resistance, *r*. Let the time, *t*, be noted at the end of which the potential of the body has fallen to *p*. The rate of loss of electricity will then be $\frac{p}{sr}$. Hence $p=\mathrm{P}\epsilon^{-\frac{t}{sr}}$ and $\frac{t}{sr}=\log_\epsilon\frac{\mathrm{P}}{p}$. Hence

$$r=\frac{t}{s\log_\epsilon\frac{\mathrm{P}}{p}}; \quad \dots\dots\dots\dots \quad (27)$$

from which equation *r* can be deduced, if *s*, *t*, and the ratio $\frac{\mathrm{P}}{p}$ be known, *t* can be directly observed, *s* can be measured (40), and the ratio $\frac{\mathrm{P}}{p}$ can be measured measurements will give v^2. This method would probably yield very accurate results.

---

* Paper read before the Royal Society, February 1860. *Vide* Proceedings of the Royal Society, vol. x. p. 319, and Phil. Mag. vol. xx. 4th ser. (1860) p. 233.

† A bifilar suspension is now used (1872).

Part V.—Electrical Measurements derived from the Five Elementary Measurements; and Conclusion.

47. *Electric Potential.*—The word "potential," as applied by G. Green to the condition of an electrified body and the space surrounding it, is now coming into extensive use, but is perhaps less generally understood than any other electrical term. Electric potential is defined by Prof. W. Thomson as follows*:

"The potential, at any point in the neighbourhood of or within an electrified body, is the quantity of work that would be required to bring a unit of positive electricity from an infinite distance to that point, if the given distribution of electricity remained unaltered."

It will be observed that this definition is exactly analogous to that given of magnetic potential (10), with the substitution of the unit quantity of electricity for the unit magnetic pole. (Analogous definitions might be given of gravitation potential, heat potential; and every one of these potentials coexist at every point of space quite independently one of the other.) In another paper† Professor Thomson describes electric potential as follows:—"The amount of work required to move a unit of electricity against electric repulsion from any one position to any other position is equal to the excess of the electric potential of the first position above the electric potential of the second position."

The two definitions given are virtually identical, since the potential at every point of infinity is zero; and it will be seen that the difference of potential defined in the second passage quoted is identical with what we have called the electromotive force between the two points (16 and 27).

When, instead of a difference of potentials, *the potential* simply of a point is spoken of, the difference of potential between the point and the earth is referred to, or, as we might say, the electromotive force between the point and the earth.

The potential at all points close to the surface and in the interior of any simple metallic body is constant; that is to say, no electromotive force can be produced in a simple metallic body by mere electrical distribution; the potential *at* the body may therefore be called the potential *of* the body. The potential of a metallic body varies according to the distribution, dimensions, position, and electrification of all surrounding bodies. It also depends on the substance forming the dielectric.

In any given circumstances, the potential of the body will be simply proportional to the quantity of electricity with which it is charged; but if the circumstances are altered, the potential will vary although the total amount of the charge may remain constant.

In a closed circuit in which a current circulates, the potential of all parts of the circuit is different; the difference depends on the resistance of each part and on the electromotive force of the source of electricity, *i. e.* on the difference of potentials which it is capable of causing when its two electrodes are separated by an insulator or dielectric. The different parts of a conductor moving in a magnetic field are maintained at different potentials, inasmuch as we have shown that an electromotive force is produced in this case. The potential of a body moving in an electric field (*i. e.* in the neighbourhood of electrified bodies) is constantly changing, but at any given moment the potential of all the parts is equal. The use of the word "potential" has the following advantages: it enables us to be more concise than if we were continually obliged to use the circumlocution, "electromotive force between the point and the earth;" and it avoids the conception of a force capable of generating a current, which almost necessarily, although falsely, is attached to "electromotive force."

---

* Paper read before the British Association, 1852. *Vide* Phil. Mag. 1853, p. 288.

† Paper read before the Royal Society, February 1860. *Vide* Proceedings of the Royal Society, vol. x. p. 334.

Equipotential surfaces and lines of force in an electric field may be constructed for statically electrified bodies; these surfaces and lines may be drawn on similar principles and possess analogous properties to those described in a magnetic field (10). It is hardly necessary to observe that the magnetic and the electric fields are totally distinct, and coexist without producing any mutual influence or interference.

The rate of variation of electric potential per unit of length along a line of force is at any point equal to the electrostatic force at that point, *i. e.* to the force which a unit of electricity placed there would experience. The unit difference of potential is identical with the unit electromotive force; and the electrometer spoken of as measuring electromotive force measures potentials or differences of potential.

48. *Density, Resultant Electric Force, Electric Pressure.*—The three following definitions are taken almost literally from a paper by Professor W. Thomson*. Our treatise would be incomplete without reference to these terms, and Professor Thomson's definitions can hardly be improved.

"*Electric Density.*—This term was introduced by Coulomb to designate the quantity of electricity per unit of area in any part of the surface of a conductor. He showed how to measure it, though not in absolute measure, by his proof-plane.

"*Resultant Electric Force.*—The resultant force in air or other insulating fluid in the neighbourhood of an electrified body is the force which a unit of electricity concentrated at that point would experience if it exercised no influence on the electric distributions in its neighbourhood. The resultant force at any point in the air close to the surface of a conductor is perpendicular to the surface, and equal to $4\pi\rho$, if ρ designates the electric density of the surface in the neighbourhood.

"*Electric Pressure from the Surface of a Conductor balanced by Air.*—A thin metallic shell or liquid film (as, for instance, a soap-bubble), if electrified, experiences a real mechanical force in a direction perpendicular to the surface outwards, equal in amount per unit of area to $2\pi\rho^2$, ρ denoting, as before, the electric density at the part of the surface considered. In the case of a soap-bubble its effect will be to cause a slight enlargement of the bubble on electrification with either vitreous or resinous electricity, and a corresponding collapse on being perfectly discharged. In every case we may consider it as constituting a deduction from the amount of air-pressure which the body experiences when unelectrified. The amount of deduction being different in different parts according to the square of the electric density, its resultant action on the whole body disturbs its equilibrium, and constitutes in fact the resultant electric force experienced by the body."

49. *Tension.*—The use of this word has been intentionally avoided by us in this treatise, because the term has been somewhat loosely used by various writers, sometimes apparently expressing what we have called the density,

---

* Paper read before the Royal Society, Feb. 1860. *Vide* Proc. R. S. vol. x. p. 319 (1860), and Phil. Mag. vol. xx. ser. 4 (1860), p. 322.

and at others diminution of air-pressure. By some writers it has been used in the sense of a magnitude proportional to potential or difference of potentials, but without the conception of absolute measurement, or without reference to the idea of work essential in the conception of potential.

50. *Conducting Power, Specific Resistance, and Specific Conducting Power.*

Conducting Power, or Conductivity.—These expressions are employed to signify the reciprocal of the resistance of any conductor. Thus, if the resistance of a wire be expressed by the number 2, its conducting power will be 0·5.

Specific Resistance referred to unit of Mass.—The specific resistance of a material at a given temperature may be defined as the resistance of the unit mass formed into a conductor of unit length and of uniform section. Thus the specific resistance of a metal in the metrical system is the resistance of a wire of that metal one metre long and weighing one gramme. If the centimetre is used as the fundamental unit, the specific resistance of a metal is the resistance of a wire of that metal one centimetre long and weighing one gramme.

The Specific Conducting Power of a material is the reciprocal of its specific resistance.

Specific resistance, referred to unit of volume, is the resistance opposed by the unit cube of the material to the passage of electricity between two opposed faces. It may easily be deduced from the specific resistance referred to unit of mass, when the specific gravity of the material is known.

Specific Conducting Power may also be referred to unit of volume. It is of course the reciprocal of the specific resistance referred to the same unit.

It is somewhat more convenient to refer the resistance to the unit of mass in the case of long uniform conductors, such as metal wires, of which the size is frequently and easily measured by the weight per foot or metre or centimetre; and it is, on the other hand, more convenient to refer to the unit of volume bodies, such as gutta percha, glass, &c., which do not generally occur as conducting-rods of uniform section, while their dimensions can always be measured with at least as much accuracy as their weights.

51. *Specific Inductive Capacity*[*].—Faraday discovered that the capacity of a conductor does not depend simply on its dimensions or on its position relatively to other conductors, but is influenced in amount by the nature of the insulator or dielectric separating it from them. The laws of induction are assumed to be the same in all insulating materials, although the amount be different. The name "inductive capacity" is given to that quality of an insulator in virtue of which it affects the capacity of the conductor it surrounds; and this quality is measured by reference to air, which is assumed to possess the unit inductive capacity. The specific inductive capacity of a material is therefore equal to the quotient of the capacity of any conductor insulated by that material from the surrounded conductors, divided by the capacity of the same conductor in the same position separated from them by air only. It is not improbable that this view of induction may be hereafter modified.

52. *Heat produced in a Conductor by a Current.*—The work done in driving a current, C, for a unit of time through a conductor whose resistance is R, by an electromotive force E, is $EC = RC^2$ (§ 17). This work is lost as electrical energy, and is transformed into heat. As Dr. Joule has ascertained the quantity of mechanical work equivalent to one unit of heat, we can calculate

---

[*] Experimental Researches, series xi.

the quantity of heat produced in a conductor in a given time, if we know C and R in absolute measure. In the series of units founded on the centimetre, gramme, and second, if we call the total heat Θ, taking as unit the quantity required to raise one gramme of water one degree Centigrade, we have

$$\Theta=\frac{\mathrm{RC}^2t}{4157\times 10^4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

If the metre is used instead of the centimetre the divisor is 4157; and in the British system, founded on feet, grains, and seconds, with a unit of heat equal to the quantity required to raise one grain one degree Fahrenheit, the divisor is 24·861.

53. *Electrochemical Equivalents.*—Dr. Faraday has shown * that when an electric current passes through certain substances and decomposes them, the quantity of each substance decomposed is proportional to the quantity of electricity which passes. Hence we may call that quantity of a substance which is decomposed by unit current in unit time the electrochemical equivalent of that substance.

This equivalent is a certain number of grammes of the substance. The equivalents of different substances are in the proportion of their combining numbers; and if all chemical compounds were electrolytes, we should be able to construct experimentally a table of equivalents in which the weight of each substance decomposed by a unit of electricity would be given. The electrochemical equivalent of water, in electro-magnetic measure, is about 0·02 in the British, 0·00092† in the centimetrical system, and ·0092 in the metrical system. The electrochemical equivalents of all other electrolytes can be deduced from this measurement with the aid of their combining numbers.

54. *Electromotive Force of Chemical Affinity.*—When two substances having a tendency to combine are brought together and enter into combination, they enter into a new state, in which the intrinsic energy of the system is generally less than it was before, that is, the substances are less able to effect chemical changes, or to produce heat or mechanical action, than before.

The energy thus lost appears during the combination as heat or electrical or mechanical action, and can be measured in many cases ‡.

The energy given out during the combination of two substances may, like all other forms of energy, be considered as the product of two factors §—the tendency to combine, and the amount of combination effected. Now the amount of combination may be measured by the number of electrochemical equivalents which enter into combination; so that the tendency to combine may also be ascertained by dividing the energy given out by the number of electrochemical equivalents which enter into combination.

If the whole energy appears in the form of electric currents, the energy of the current is measured by the product of the electromotive force and the quantity of electricity which passes. Now the quantity of electricity which passes is equal to the number of electrochemical equivalents which enter on either side into combination. Hence the total energy given out, divided by this number, will give the electromotive force of combination. Thus, if N electrochemical equivalents enter into combination under a chemical affinity I, and in doing so give out energy equal to W, either as heat or as electrical action, then

---

* Experimental Researches, series vii.

† ·0009375 by Weber and Kohlrausch.

‡ Report British Association, 1850, p. 63, and Phil. Mag. vol. xxxii. ser. 3. See papers by Prof. Andrews, and Favre and Silbermann, "On the Heat given out in Chemical Action," otes Rendus, vols. xxxvi. & xxxvii.

Rankine "On the General Law of Transformation of Energy," Phil. Mag. 1853.

$$NI = W.$$

But if W be given out as electrical action, and causes a quantity of electricity Q to traverse a conductor under an electromotive force E, we shall have

$$W = EQ.$$

By the definition of electrochemical equivalents, $Q = N$, therefore

$$I = E;$$

or the force of chemical affinity may in these cases be measured as electromotive force.

This method of ascertaining the electromotive force due to chemical combination, which gives us a clear insight into the meaning and the measurement of "chemical affinity," is due to Professor W. Thomson[*].

The field of investigation presented to us by these considerations is very wide. We have to measure the intrinsic energy of substances as dependent on volume, temperature, and state of combination. When this is done, the energy due to any combination will be found by subtracting the energy of the compound from that of the components before combination.

As the tendency to increase in volume is measured as pressure, and as the tendency to part with heat is measured by the temperature, so in chemical dynamics the tendency to combine will be properly measured by the electromotive force of combination.

55. *Tables of Dimensions and other Constants*[†] :—

Fundamental Units.

Length = L. Time = T. Mass = M.

Derived Mechanical Units.

$$\text{Work} = W = \frac{L^2 M}{T^2}. \qquad \text{Force} = F = \frac{LM}{T^2}. \qquad \text{Velocity} = V = \frac{L}{T}.$$

Derived Magnetical Units.

Strength of the pole of a magnet .... $m = L^{\frac{3}{2}} \; T^{-1} M^{\frac{1}{2}}$

Moment of a magnet .... $ml = L^{\frac{5}{2}} \; T^{-1} M^{\frac{1}{2}}$

Intensity of magnetic field.......... $H = L^{-\frac{1}{2}} T^{-1} M^{\frac{1}{2}}$

---

[*] "On the Mechanical Theory of Electrolysis," Phil. Mag. Dec. 1851.

[†] The first Table of Dimensions was given by Fourier, 'Théorie de la Chaleur,' p. 157.

Table for the Conversion of British (foot-grain-second) System to Centimetrical (centimetre-gramme-second) System.

	Number of centimetrical units contained in a British unit.	Number of British units contained in a centimetrical unit.
1° for M	0·0647989	15·43235
2° for L, $\frac{v}{1}$ R, $\frac{1}{r}$ and V	30·47945	·03280899
3° for F (also for foot-grains and centimetre-grammes).	1·97504	·506320
4° for W	60·198	·01661185
5° for H and electrochemical equivalents.	·0461085	21·6880
6° for Q, C, and e	1·40536	·711561
7° for E, m, q, and c	42·8346	·0233456
8° for heat	0·0359994	27·7782

1 volt........ $=10^8$ absolute units of electromotive force.
1 ohm ...... $=10^9$ centimetres per second.
„ ...... $=3{\cdot}2809\times10^7$ feet per second.
„ ...... =1 quadrant of the meridian through Paris per second.
v............ =31·074 ohms by Weber and Kohlrausch.
„ .... =28·2 ohms by Thomson.
„ .... =28·8 ohms by Maxwell.
Velocity of light=29·8 ohms by Foucault.

The intensity of gravity at many different stations has been determined by experiment. Where it has not been so determined, it may be calculated by the formula

$$g=G\,(1-0{\cdot}0025659\cos 2\lambda)\left\{1-\left(2-\frac{3}{2}\frac{\rho'}{\rho}\right)\frac{z}{r}\right\},$$

where g denotes the intensity of gravity at the station.

G the intensity of gravity at latitude 45° at the level of the sea.

G=980·533 centimetres, or 32·1703 feet.

λ is the latitude of the station.

The last factor is a correction for the height of the station.

z is the height of the station in centimetres or feet.

r is the mean radius of the earth.

r=636,619,800 centimetres, or 20,886,852 feet; ρ is the mean density of the earth, about 5·5 times that of water; ρ' is the mean density of the hill on which the station is placed. If we suppose this about half the density of the earth as a whole, the factor for correction due to height becomes

$$1-1{\cdot}32\frac{z}{r}, \text{ nearly.}$$

The absolute magnitude is in most cases an inconvenient one, leading to the use either of exceedingly small or exceedingly large numbers. Thus the units of electro-magnetic resistance and electromotive force and quantity, and of electrostatic currents, are inconveniently small; the unit of electrostatic resistance is inconveniently large. Decimal multiples and submultiples of these units will therefore probably have to be adopted in practice. The choice of these multiples and submultiples forms part of the business of the Committee.

The nomenclature hitherto adopted is extremely defective. In referring to each measurement, we have to say that the number expresses the value in electrostatic or electro-magnetic absolute units: if a multiple is to be used, this multiple will also have to be named; and further, the standard units of length, mass, and time have to be referred to, inasmuch as some writers use the pound and some the grain, some the metre and some the millimetre, as fundamental units. This cumbrous diction, and the risk of error imported by it, would be avoided if each unit received a short distinctive name in the manner proposed by Sir Charles Bright and Mr. Latimer Clark, in a paper read before the British Association at Manchester, 1861.

TABLE OF CONTENTS.

Part I.—INTRODUCTORY.

1. Objects of treatise.
2. Derivation of units from fundamental standards.
3. Standard mechanical units.
4. Dimensions of derived units.

Part II.—THE MEASUREMENT OF MAGNETIC PHENOMENA.

5. Magnets and magnetic poles.
6. Magnetic field.
7. Magnetic moment.
8. Intensity of magnetization.
9. Coefficient of magnetic induction.
10. Magnetic potentials and equipotential surfaces.
11. Lines of magnetic force.
12. Relation between lines of force and equipotential surfaces.

Part III.—MEASUREMENT OF ELECTRIC PHENOMENA BY THEIR ELECTRO-MAGNETIC EFFECTS.

13. Preliminary.
14. Meaning of the words "electric quantity."
15. Meaning of the words "electric current."
16. Meaning of the words "electromotive force."
17. Meaning of the words "electric resistance."
18. Measurement of electric currents by their action on a magnetic needle.
19. Measurement of electric currents by their mutual action on one another.
20. Weber's Electro-dynamometer.
21. Comparison of the electro-magnetic and electrochemical action of currents.
22. Magnetic field near a current.
23. Mechanical action of a magnetic field on a closed conductor conveying a current.
24. General law of the mechanical action between electric currents and other electric currents or magnets.
25. Electro-magnetic measurement of electric quantity.
26. Electric capacity of a conductor.
27. Direct measurement of electromotive force.
28. Indirect measurements of electromotive force.
29. Measurement of electric resistance.
30. Electric resistance in electro-magnetic units is measured by an absolute velocity.
31. Magneto-electric induction.
32. On material standards for the measurement of electric magnitudes.

Part IV.—MEASUREMENT OF ELECTRIC PHENOMENA BY STATICAL EFFECTS.

33. Electrostatic measure of electric quantity.
34. Electrostatic system of units.
35. Ratio between electrostatic and electro-magnetic measures of quantity.
36. Electrostatic measure of currents.
37. Electrostatic measure of electromotive force.
38. Electrostatic measure of resistance.
39. Electric resistance in electrostatic units is measured by the reciprocal of an absolute velocity.
40. Electrostatic measure of the capacity of a conductor.
41. Absolute condenser. Practical measurement of quantity.
42. Practical measurement of currents.
43. Practical measurement of electromotive force.
44. Comparison of electromotive forces by their statical effects.
45. Practical measurement of electric resistance.
46. Experimental determination of the ratio v between electro-magnetic and electrostatic measures of quantity.

Part V.—ELECTRICAL MEASUREMENTS DERIVED FROM THE FIVE ELEMENTARY MEASUREMENTS.

47. Electric potential.
48. Density, resultant electric force, electric pressure.
49. Tension.
50. Conducting power, specific resistance, and specific conducting power.
51. Specific inductive capacity.
52. Heat produced in a conductor by a current.
53. Electrochemical equivalents.
54. Electromotive force of chemical affinity.
55. Tables of dimensions and other constants.
56. Magnitude of units and nomenclature.

APPENDIX D.—*Description of an Experimental Measurement of Electrical Resistance, made at King's College. By* Professor J. CLERK MAXWELL *and* Messrs. BALFOUR STEWART *and* FLEEMING JENKIN. (Parts I., III., and IV., by Professor MAXWELL. Part II., by Mr. FLEEMING JENKIN.)

Part I.—GENERAL DESCRIPTION OF THE METHOD EMPLOYED.

In the general Report of the Committee, and in Appendix C, it has already been shown that the most important aid to the exact science of electricity would be the determination of the resistance of a wire in absolute measure, and the publication of standards of resistance derived from this wire. This has already been done by Weber*; but it is desirable that the determination of a quantity so important should not be left in the hands of a single person.

Weber has employed two methods.

1st. By suddenly turning a coil of wire about an axis so as to alter its position relatively to the terrestrial magnetic lines of force, he produced an electromotive force acting for a short time in the coil. This coil was connected with another fixed coil having a magnet suspended in its centre. The current generated by the electromotive force passed through both coils and

---

d. lxxxii. p. 337 (March 1851); Electrische Maasbestimmungen, Leipzig,
rs of the Royal Society of Sciences of Saxony, vol. i. p. 197; and

The absolute magnitude is in most cases an inconvenient one, leading to use either of exceedingly small or exceedingly large numbers. Thus the s of electro-magnetic resistance and electromotive force and quantity, and lectrostatic currents, are inconveniently small: the unit of electrostatic stance is inconveniently large. Decimal multiples and submultiples of e units will therefore probably have to be adopted in practice. The ese of these multiples and submultiples forms part of the business of the mittee.

he nomenclature hitherto adopted is extremely defective. In referring ach measurement, we have to say that the number expresses the value in trostatic or electro-magnetic absolute units: if a multiple is to be used, this tiple will also have to be named: and further, the standard units of length, s, and time have to be referred to, inasmuch as some writers use the pound some the grain, some the metre and some the millimetre, as fundamental s. This cumbrous diction, and the risk of error imported by it, would avoided if each unit received a short distinctive name in the manner pro-d by Sir Charles Bright and Mr. Latimer Clark, in a paper read before British Association at Manchester, 1861.

TABLE OF CONTENTS.

Part I.—INTRODUCTORY.

Objects of treatise.
Derivation of units from fundamental standards.
3. Standard mechanical units.
4. Dimensions of derived units.

Part II.—THE MEASUREMENT OF MAGNETIC PHENOMENA.

Magnets and magnetic poles.
Magnetic field.
Magnetic moment.
ntensity of magnetization.
oefficient of magnetic induction.
10. Magnetic potentials and equipotential surfaces.
11. Lines of magnetic force.
12. Relation between lines of force and equipotential surfaces.

Part III.—MEASUREMENT OF ELECTRIC PHENOMENA BY THEIR ELECTRO-MAGNETIC EFFECTS.

Preliminary.
Meaning of the words "electric quantity."
Meaning of the words "electric current."
Meaning of the words "electromotive force."
Meaning of the words "electric resistance."
Measurement of electric currents by their action on a magnetic needle.
Measurement of electric currents by their mutual action on one another.
Weber's Electro-dynamometer.
Comparison of the electro-magnetic and electrochemical action of currents.
Magnetic field near a current.
Mechanical action of a mag on a closed conductor conveying a current.
24. General law of the mechanical action between electric currents and other electric currents or magnets.
25. Electro-magnetic measurement of electric quantity.
26. Electric capacity of a conductor.
27. Direct measurement of electromotive force.
28. Indirect measurements of electromotive force.
29. Measurement of electric resistance.
30. Electric resistance in electro-magnetic units is measured by an absolute velocity.
31. Magneto-electric induction.
32. On material standards for the measurement of electric magnitudes.

the revolving coil by a simple band $a\ a_1\ a_2$.... The arrangement of the ba $b\ b_1\ b_2$.... communicating the motion of shaft A to shaft B may be easi understood from the diagram. C C are two guide-pulleys running loose .pins attached to the main framing. D D are two loose pulleys maintained a constant distance by the strut E, to which the weight W is hung.

When the rotation of shaft B is opposed by a sufficient resistance, th effect of turning the flywheel in the direction shown by the arrow is to li the weight W from the ground, tending to turn the shaft B with a definit force, which will be sensibly constant so long as the weight is kept off th ground and the band $b\ b_1\ b_2$.... remains unaltered in length. Wherever, in the present experiments, the resistance increases with the speed of rotation, the speed of the driving-wheel can easily be regulated by hand, so as t keep the weight from falling so low as to touch the ground, or rising so hig as to foul the gear; and thus, with a little care, a constant driving force ca be applied to the shaft B and to the machinery connected with it.

The *revolving coil* formed the most important part of the apparatus. It i shown one-fifth full size in figs. 1 and 2, Pl. II.

A strong brass frame, H H, was bolted down by three brass bolts, F F F, dowelled into a heavy stone. It could be accurately levelled by three stou screws, G G G. The brass rings, I I_1, on which the insulated copper wir was coiled, were supported on the frame by a pivot, J, working in lignu vitæ, and by a hollow bearing, K, working in brass: this bearing worked i a kind of stuffing-box, *k* (fig. 3), which, by three screws and a flat sprin washer between it and the frame at *j*, could be adjusted to fit the collar with great nicety, preventing all tendency to bind or shake. Supported i this way the coil revolved with the utmost freedom and steadiness.

The coil of copper wire was necessarily divided into two parts on the tw rings I I_1, to permit the suspension of the magnet S. The two brass ring were each formed of two distinct halves, insulated from one another by vulcanite at the flanges $f\,f_1$. This insulation was necessary to prevent the induction of currents in the brass rings. These rings, after being bolte together, were turned with great accuracy by Messrs. Elliott Brothers. Th insulated copper wire was wound in one direction on both rings; the inne end of the second was soldered to the outer end of the first; the two extreme ends of the conductor thus formed were soldered to two copper terminals, $h\ h'$, insulated by the vulcanite piece, *x*, bolted to the brass rings. Each terminal was provided with a strong copper binding-screw, and had a mercury-cup drilled into its upper surface. The two coils could be joined, so as to form closed circuit, by a short copper bar between the binding-screws. The bars, binding-screws, and nuts were amalgamated to ensure perfect contact. When the copper coils were to be connected with the electric balance, the short copper bar was removed and the required connexions were made by short copper rods, one quarter of an inch in diameter, dipping at one end into the mercury-cup on the terminals $h\ h'$, and at the other end into the mercury-cups of the electric balance. The absence of all induced currents influencing the suspended magnet when the circuit was broken at $h\ h'$ was repeatedly proved by experiment.

Rotation was communicated to the coils by a catgut band simply making half a turn round the small V-pulley *l*. The band could be tightened as required by the jockey pulley *z* and weight *w* (fig. 4).

A short screw of large diameter, *n*, gearing into a spur-wheel of one hundred teeth, *o*, formed the counter from which the speed of rotation was obtained, as follows:—A pin, *p*, on the wheel *o* lifted the spring *q* as it sed; this spring in its rebound struck the gong M. The blow was of rse repeated at every hundred revolutions, and the time of each blow was served on a chronometer. The arrangement was equally adapted for rota- n in either direction.

A second V-pulley, *r*, served for the band *c c*, communicating motion to the vernor by which the speed was controlled.

The manner in which the suspended magnet was introduced to the centre the coil is best seen in fig. 3. A brass tripod, N, bolted to the main me, supported the long brass tube O, which passed freely through the llow bearing at K. A cylindrical wooden box, P, slipped on to the end of e tube O. The magnet hung inside this box, the lower part of which ld be removed to allow the exact position of the magnet to be verified. e support N also carried a short brass tube R, on which the glass case ould be secured by a little sliding tube. The mirror *t*, attached to the gnet S by a rigid brass wire, hung inside this glass case by a single oon-fibre about eight feet long. This fibre was protected against currents air by a wooden case (not shown in the Plate), extending from the point support down to the glass case. A little sliding paper prolongation of the oden case made it nearly wind-proof by fitting at the bottom against the n brass frame. An opening in the case allowed the mirror to be seen. e fibre at the top was suspended from a torsion-head, by which it could turned; it could also be raised and lowered by a small barrel, and was ustable in a horizontal plane by three set screws. The care taken in sus- ding the magnet and in protecting it both against currents of air and ration was repaid by success, for the image of the scale reflected in the gnet was as clear and steady when the coil was making 400 revolutions minute as when it was at rest.

he *governor* used was lent by one of the Committee and will not be ribed in detail, as an improved governor on the same principle will be pted in future experiments, in describing which an account of its construc- will be given. It may be said, however, that the little instrument actually loyed generally controlled the speed to such uniformity as allowed the ctions to be observed with as much accuracy as the zero-point.

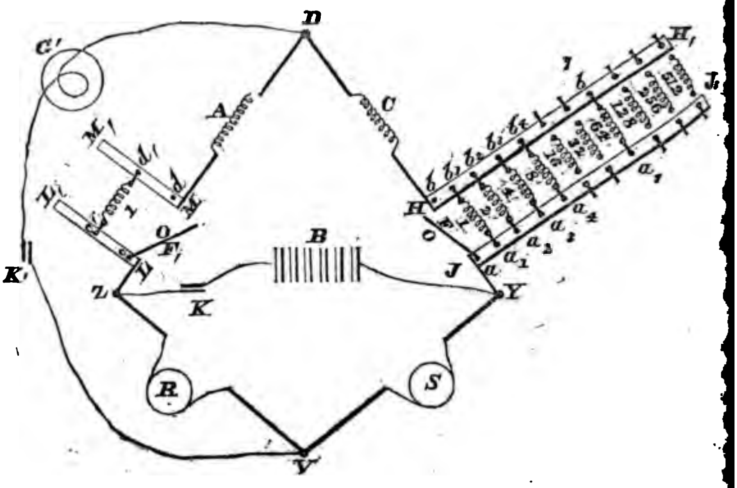
he *scale* and *telescope* hardly require special description; they were nged in the usual manner for this kind of experiment, at about three res from the mirror. The scale was an engine-divided paper scale nailed a wooden bar. This plan will in future experiments be abandoned, as iations in the weather had a very perceptible influence on the scale.

he annexed (p. 100) diagram shows the *electric balance* by which the copper C was compared with an arbitrary German-silver standard S before and r each induction experiment. The arrangement is that of the ordinary atstone's balance, as described in Appendix H of the Report of your mittee for 1862. A and C represent the arms of the balance as there ribed, S the German-silver standard, and R the copper coil to be mea- d. J J_1, H H_1, M M_1, and L L_1 are four stout copper bars with mercury- s at $a\,a_1\,a_2\,.\,.$, $b\,b_1\,b_2\,.\,.$, $c\,c_1$, and $d\,d_1$. Two short copper rods, F and F_1, can used to connect *a* with *b* and *c* with *d*. When this is done the arrange- t is exactly that of the simple Wheatstone balance with the keys at K K_1, and described in Appendix H of the last Report. A and C were coils med of about 300 inches of No. 31* German-silver wire, and were adjusted equality with extreme nicety, and each assumed equal to 100 arbitrary s. If R on any occasion had been exactly equal to S, the galvanometer G′

---

* Diameter =0·01 inch.

would have been unaffected on depressing the keys $K K_1$, when *a* was jo to *b* and *c* to *d* by F and F_1, rods of no sensible resistance. This exact equa between R and S could never be obtained, owing to slight changes in temp ture, which affected.the two coils very differently. The object of the modi



tions introduced was to allow the ratio between S and R, differing by a amount only, to be measured with great accuracy.

For this purpose a number of German-silver coils were adjusted, repres ing 1, 2, 4, 8 .... 512 in the arbitrary units, equal to the hundredth part or C. These coils were so arranged that any one or more of them coul introduced between the bars $H H_1$ and $J J_1$. A single coil, equal to 1 in same arbitrary unit, could be introduced between the bars $L L_1$ and M In the diagram this coil is shown in its position and the rod F_1 withdr Similarly F is withdrawn from between H and G′, and the coil 1 joins a_1 b_1 in the bars $H H_1$ and $J J_1$. If no other coils were placed between $H H_1$ $J J_1$, the arms of the balance would now be 101 and 101 respectively, ins of 100 and 100; but the ratio would still be that of equality. Let us suppose that, when the circuit with the battery is completed, the galvano by its deflection shows that R is bigger than S, we can reduce the resist of the arm between D and Y by various small graduated and definite amo by introducing the coils 2, 4, 8, &c. between $H H_1$ and $J J_1$. Let us suppose the coil 2 introduced. The resistance between H and J will be reciprocal of 1·5 or 0·6667; for where various resistances are adde multiple arc, the resistance of the compound arc is the reciprocal of sum of their conducting powers, and the conducting power of a wire is reciprocal of its resistance. The ratio between the two arms will no 101 : 100·6667. Let us suppose that on completing the circuit the galv meter still deflects in the same direction as before, the arm between D a must be still further reduced by including fresh coils between $H H_1$ and It is very easy by trial to find the combination which maintains the galv meter at zero when the circuit is completed. Let us suppose that, as in diagram, the coils included were 1, 2, 4, 8, and 64. The reciproca these numbers are 1, 0·5, 0·25, 0·125, and 0·015625. The conducting p etween H and J is therefore 1·890625, the sum of these numbers. The esistance between H and J is 0·52893, the reciprocal of the last number, and he ratio between the arms will be 101 : 100·52893. A little consideration ill show that with the coils named any ratio between 101 to 100·5 and 101 101 can be obtained by steps not exceeding 0·00195, the reciprocal of 512, he largest coil or smallest conducting power which can be included between he copper bars HH_1 and JJ_1. By substituting the rod F for the coil 1 beween LL_1 and MM_1, the observer can obtain a fresh series of ratios with the ame steps between 101 to 100 and 100·5 to 100. In this way it will be seen hat unless the coils R and S differ by more than one per cent., their ratio an be measured in the manner described within 0·002 per cent.

It should further be observed that extreme accuracy in the coils 1, 2, 4, c. is not necessary, since an error of one per cent. in the sum of these, as ompared with their true relative value to the coil C, would only affect the nal result 0·01 per cent.

The position of R and S in the balance relatively to A and C, &c. is of course interchangeable.

The diagram is not intended at all to represent the practical arrangement, but simply to show the connexions. The electric balance described in Appendix H of last year's Report (Plate I. figs. 1 to 6, Report 1862) was used with a stout copper rod between the cups ee_1, and two additional boards with the copper bars HH_1, JJ_1, LL_1, and MM_1 fitted as in the above diagram. The coils 1, 2, 4, &c. had amalgamated copper terminals, which simply dropped into mercury-cups on the copper bars. The observations could be made very apidly and accurately, as the galvanometer was sensitive enough with four aniell's cells to indicate the addition or subtraction of the 512 coil with per-ct distinctness. The reduction of the observations to find the ratio seems mewhat complicated at first, but with the aid of a table of reciprocals it kes but little time. No improvement seems necessary in this part of the paratus. The idea of using large coils combined with small ones in mulple arc to obtain extremely minute differences of resistance was suggested to e writer by Professor W. Thomson, and will be found useful in very many ays.

Part III.—MATHEMATICAL THEORY OF THE EXPERIMENT.

A circular coil of copper wire is made to revolve with uniform velocity out a vertical diameter. A small magnet is suspended by a silken fibre in e middle of the coil. Its position is observed when the coil is at rest, and hen the coil revolves with velocity ω the magnet is deflected through an gle ϕ. Currents are induced in the coil by the action of the earth's magtism, and these act on the magnet and deflect it from the magnetic merian. By observing the deflection and the velocity of rotation, we can deterine the resistance of the coil in electro-magnetic units.

In determining the strength of the current we may neglect the motion of e suspended magnet, as it is found, both by theory and by experiment, to e insensible. We have therefore, in the first place, to determine the electrognetic potential of the coil with respect to the earth's magnetism, with pect to the suspended magnet, and with respect to itself.

1st. Let H be the horizontal component of the earth's magnetism.

γ the strength of the current in the coil.

G the total area enclosed by all the windings of the wire.

θ the angle between the plane of the coil and the magnetic meridian.

Then the potential of the coil with respect to the earth is

$$-\mathrm{H}\gamma\mathrm{G}\sin\theta.$$

2nd. Let M be the magnetic moment of the suspended magnet.

ϕ the angle between the axis of the magnet and the magneti meridian.

K the magnetic force at the centre of the coil due to unit curre in the wire.

Then the potential of the coil with respect to the magnet is

$$-\mathrm{M}\gamma\mathrm{K}\sin(\theta-\phi).$$

3rd. Let $\frac{1}{2}$L be the potential of the coil on itself for unit current. Then the potential due to a current γ is

$$\tfrac{1}{2}\mathrm{L}\gamma^2.$$

Let P be the electromotive force, and R the resistance, then the wor spent in keeping up the current is Pγ in unit of time; or, since $\mathrm{P}=\mathrm{R}\gamma$, th work spent in keeping up the current for a time δt is

$$\mathrm{R}\gamma^2\,\delta t.$$

If the current is at the same time increased from γ to $\gamma+\delta\gamma$, the wor spent in increasing the current will be

$$\mathrm{L}\gamma\,\delta\gamma.$$

If the angular motion of the coil be $\delta\theta$, the work spent in keeping up t rotation against the electro-magnetic force is

$$\mathrm{H}\gamma\mathrm{G}\cos\theta d\theta+\mathrm{M}\gamma\mathrm{K}\cos(\theta-\phi)d\theta.$$

Since this work is exactly consumed in keeping up or increasing the curren we must have

$$\mathrm{H}\gamma\mathrm{G}\cos\theta d\theta+\mathrm{M}\gamma\mathrm{K}\cos(\theta-\phi)d\theta=\mathrm{R}\gamma^2dt+\mathrm{L}\gamma d\gamma.$$

Since $\theta=\omega t$ and $\frac{d\theta}{dt}=\omega$, the solution of this equation is

$$\gamma=\frac{\omega}{\mathrm{R}^2+\mathrm{L}^2\omega^2}\{\mathrm{GH}(\mathrm{R}\cos\theta+\mathrm{L}\omega\sin\theta)+\mathrm{KM}\big(\mathrm{R}\cos(\theta-\phi)+\mathrm{L}\omega\sin(\theta-\phi)\big)\}$$
$$+\mathrm{C}\epsilon^{-\frac{\mathrm{R}}{\mathrm{L}}t},$$

the last term becoming insensible soon after the beginning of the experime

We can now find the equation of motion of the magnet.

Let A be its moment of inertia, MHτ the torsion of the fibre per unit angular rotation, then

$$\mathrm{A}\frac{d^2\phi}{dt^2}=\mathrm{MK}\gamma\cos(\phi-\theta)-\mathrm{MH}(\sin\phi+\tau\phi).$$

Substituting the value of γ and separating terms in θ, we find

$$\mathrm{A}\frac{d^2\phi}{dt^2}=\frac{1}{2}\frac{\mathrm{MK}\omega}{\mathrm{R}^2+\mathrm{L}^2\omega^2}\Big\{\mathrm{GH}(\mathrm{R}\cos\phi+\mathrm{L}\omega\sin\phi)+\mathrm{KMR}\Big\}-\mathrm{MH}(\sin\phi-\mathrm{T}\phi)$$
$$+\frac{1}{2}\frac{\mathrm{MK}\omega}{\mathrm{R}^2+\mathrm{L}^2\omega^2}\Big\{\mathrm{GH}\big(\mathrm{R}\cos(2\theta-\phi)+\mathrm{L}\omega\sin(2\theta-\phi)\big)$$
$$+\mathrm{KM}\big(\mathrm{R}\cos 2(\theta-\phi)+\mathrm{L}\omega\sin 2(\theta-\phi)\big)\Big\}.$$

In order that ϕ may continue as it does nearly constant, the part independent of θ must vanish, or

$$\frac{1}{2}\frac{\mathrm{MK}\omega}{\mathrm{R}^2+\mathrm{L}^2\omega^2}\left\{\mathrm{GH}(\mathrm{R}\cos\phi+\mathrm{L}\omega\sin\phi)+\mathrm{KMR}\right\}-\mathrm{MH}(\sin\phi+\mathrm{T}\phi)=0.$$

This gives the following quadratic equation for R:—

$$\mathrm{R}^2-\frac{1}{2}\mathrm{R}\frac{\mathrm{GK}\omega}{\sin\phi+\tau\phi}\left(\cos\phi+\frac{\mathrm{KM}}{\mathrm{GH}}\right)=\frac{1}{2}\frac{\mathrm{GKL}\omega^2}{1+\tau\frac{\phi}{\sin\phi}}-\mathrm{L}\omega^2.$$

The solution of this equation may be expressed to a sufficient degree of accuracy as follows:—

$$\mathrm{R}=\frac{\mathrm{GK}\omega}{2\tan\phi(1+\tau)}\left\{1+\frac{\mathrm{KM}}{\mathrm{GH}}\sec\phi-\frac{2\mathrm{L}}{\mathrm{GK}}\left(\frac{2\mathrm{L}}{\mathrm{GK}}-1\right)\tan^2\phi\right\}.$$

To determine the quantities occurring in this equation, we must measure the dimensions of the coil, the strength of the magnet, and the force of torsion of the fibre.

1st. Dimensions of the coil.

Let a = mean radius of the coil .... = 0·1566 metre.
n = number of windings of wire .... = 307
l = effective length of wire = $2\pi na$.............. = 302·063 metres.
b = breadth of section of coil perpendicular to the plane of the coil .... = ·0185 metre.
c = depth of section in the plane of the coil ...... = ·0132 „
b' = distance of mean plane of coil from axis of motion .... = ·01915 „
α = angle subtended at axis by radius of coil = 83° 1′.

$$\cos\alpha=\frac{b'}{a}=\cdot 12245.$$

Then $\mathrm{G}=\pi na^2\left(1+\frac{1}{12}\frac{c^2}{a^2}\right)$,

$$\mathrm{K}=\frac{2\pi n}{a}\sin^3\alpha\left\{1+\frac{1}{24}\frac{c^2}{a^2}(2-15\sin^2\alpha\cos^2\alpha)\right.$$
$$\left.+\frac{1}{24}\frac{b^2}{a^2}(15\sin^2\alpha\cos^2\alpha-3\sin^2\alpha)\right\},$$

$$\mathrm{GK}=\pi nl\sin^3\alpha\left\{1+\frac{1}{6}\frac{c^2}{a^2}+\frac{5}{8}\frac{b^2-c^2}{a^2}\sin^2\alpha\cos^2\alpha-\frac{1}{8}\frac{b^2}{a^2}\sin^2\alpha\right\}.$$

If the dimensions of the coil are measured in metres, GK will be expressed in metres.

Let T be the time of 100 revolutions of the coil, expressed in seconds, then

$$\mathrm{T}\omega=200\pi,$$

r

$$\omega=\frac{200\pi}{\mathrm{T}}.$$

Let D be the distance of the scale from the mirror, δ the scale-reading measured from the point of the scale which is nearest to the mirror, then

$$\tan 2\phi=\frac{\delta}{D};$$

$$\therefore \frac{1}{2\tan\phi}=\frac{D}{\delta}\left\{1+\frac{1}{4}\frac{\delta^2}{D^2}\right\}.$$

To determine MHτ, the coefficient of torsion, let the magnet be turn round so as to twist the fibre nearly 360°. Let the difference of reading d to the torsion be δ', then

$$\tau=\frac{\delta'}{4\pi D}\frac{1}{1-\frac{\delta'}{4\pi D}}.$$

To determine $\frac{KM}{GH}$, let the suspended magnet A be removed, and let anotl magnet, which we shall call B, be put in its place. Let the magnet A be n placed east or west of B, at a distance equal to the mean distance of the c or $\sqrt{a^2+b'^2}$. Let the deflection of B when the north or south end of A directed to it be μ, then

$$\frac{KM}{GH}=\tan\mu.$$

The determination of the quantity L, the electro-magnetic capacity of coil, requires a more complex calculation, which must be explained separat In the actual experiment the deviation ϕ was always small, and therel $\tan^2\phi$ was very small, so that the term depending on L was never import We may now write the value of R,

$$R=\frac{200\pi^2 Dnl\sin^3\alpha}{T\delta}\{1+\text{corrections}\}.$$

In this expression the quantities $Dnl\alpha$ are determined before the exp ment is made. The only quantities to be observed are T, the numbe seconds in 100 revolutions, and δ, the deviation in millimetres of the sca

Part IV.—DETAILS OF THE EXPERIMENTS.

In the experiments at King's College, June 1863,

n, the number of windings, was 307.

l, the effective length of wire, 302·063 metres.

$\sin^3\alpha=1-{\cdot}021756$.

D, the distance from the mirror to the scale, 2·9853 metres.

Determination of Velocity.

A wheel of 100 teeth turned by an endless screw caused a bell to be str every 100 revolutions of the coil. The times of the bells, as observed w a chronometer, serve to determine T.

Determination of Deviation.

δ is the difference between the reading of the scale when the magne acted on by the earth only, and when it is acted on also by the induced c rents in the coil. To determine δ, the reading of the scale is made when coil is at rest, or when the circuit is broken. Another reading is taken w the connexion complete and the coil in motion. If the earth's magnet remains the same, the difference of these readings is the true value of δ; but since the direction of the earth's magnetic action is continually varying, we must find the difference of *declination* between the times of the two readings, and calculate what would have been the undisturbed reading of the scale at the time when the deviation was observed.

In our experiments this correction was made by comparison with the photographic registers of magnetic declination made at Kew at the same time that our experiments were going on.

Corrections.

The corrections being small may be taken separately. Each has to be multiplied by the factor already considered,

$$R=\frac{200\pi^2 Dnl\sin^2\alpha}{T\delta}\{1+A+B+C+D+E+F+G+H+\&c.\}.$$

A. Correction for the dimensions of the section of the coil.

$$A=\frac{1}{6}\frac{c^2}{a^2}+\frac{5}{8}\frac{b^2-c^2}{a^2}\sin^2\alpha\cos^2\alpha-\frac{1}{8}\frac{b^2}{a^2}\sin^2\alpha$$
$$=+\cdot000075.$$

B. Correction for level. Let the axis of rotation be inclined to the vertical at an angle β measured towards the north, and let the angle of the dipping-needle with the horizontal be I, then there will be a correction,

$$B=-\tan I\sin\beta.$$

In the actual experiment the level was taken with a spirit-level reading to 12″, and found correct to at least that degree of accuracy.

C. Correction for the induction of the suspended magnet on the coil. The strength of the magnet, as compared with that of the magnetic field, was measured by means of a magnetometer from Kew by the ordinary method. The correction found was

$$C=+\tan\mu$$
$$=\cdot00780.$$

The small magnet generates induction-currents in the coil which react on the magnet, and tend to turn it in the direction in which the coil revolves. If there were no horizontal magnetic force due to the earth, the coil would drag the magnet round after it. In the actual case it makes the deviation greater than it should be by ·0078.

D. Correction for torsion of the fibre.

$$D=-T=-\frac{\delta'}{4\pi D}$$
$$=-\cdot00132.$$

This correction depends on the relation between the stiffness of the fibre and the directive force of the suspended magnet. The fibre was a single fibre of silk 7 feet long; the magnet was a steel sphere $\frac{5}{16}$ inch diameter, and not magnetized to saturation. The correction for torsion was therefore much larger than if a stronger magnet had been used.

E. Correction for position of suspended magnet.

Let the centre of the magnet be at a distance ζ above or below the centre of the coil, η north or south of the axis of motion, and ξ east or west of the axis, then there will be a correction,

$$E = +\frac{3}{16}(1-4\cot^2\alpha)\sin^4\alpha\left\{4\frac{\zeta^2}{a^2}-\frac{\eta^2}{a^2}-3\frac{\xi^2}{a^2}\right\}.$$

Here $a = 156\cdot6$ millimetres, and the place of the magnet was so adjusted that it could not vary one millimetre in any direction without the error being observed. Hence this correction is negligible.

F. Correction for irregularity in the magnetic field due to iron or magnets near the instrument.

Let t be the time of oscillation of a magnet at the centre of the coil, t_1 and t_2 at distances z above and below that point, then

$$F = +\frac{3a^2}{16z^2}\left\{\frac{2t-(t_1+t_2)}{t}\right\}.$$

This correction may also be neglected.

G. Correction of scale-reading. The quantity observed is $\tan 2\phi$, the quantity to be found is $\tan\phi$. The correction to the value of R is

$$+\frac{1}{4}\frac{\delta^2}{D^2}.$$

H. Correction for electro-magnetic capacity of the coil.

Let L be the value of the electro-magnetic capacity, the correction is

$$-\frac{1}{4}\frac{\delta^2}{D^2}\frac{2L}{GK}\left(\frac{2L}{GK}-1\right).$$

In the actual coil L was found by calculation $=397750$ metres, and by a rough experiment $=398500$ metres.

Now $GK = 560245$ metres.

The correction is therefore $-\frac{1}{4}\frac{\delta^2}{D^2}(0\cdot596234) = H.$

This correction is of the same form with G, and may be taken along with it.

The complete expression for R is therefore

$$R = \frac{1}{T\delta}5381455581730 + \frac{\delta}{T}\,3055\cdot5.$$

The nature of the electrical action in the experiment may be stated as follows:—

Suppose the plane of the coil to coincide with magnetic north and south, and that the coil is revolving in the direction of the hands of a watch. Then the north side of the coil is moving from west to east, and therefore experiences an electromotive force tending to produce an *upward* current. The south side of the coil is moving from east to west, and therefore there is a tendency to produce a downward current in it. If the circuit is closed there will be a current upwards on the north side, and downward on the south side round the coil.

Now this current will tend to turn the north end of the suspended magnet towards the east; but the earth's magnetic force tends to turn it towards the north; so that the actual position assumed by the magnet must depend on the relation between the strength of the current and the strength of the earth's magnetism. But the strength of the current depends only on the velocity of rotation, the resistance of the coil, and the strength of the earth's magnetism. Hence the position of the magnet will not depend on the strength of the earth's magnetism, but only on the velocity and the resistance of the coil.

We must remember that the coil in its revolution comes into other positions than that which we have mentioned. As the north side moves towards the east, the current continually diminishes till it ceases when it is due east. The current then commences in the opposite direction with respect to the coil; but since the coil itself is now in a reversed position, the effect of the current on the suspended magnet is still to turn the north end to the east. The action of the current on the magnet is therefore of an intermittent nature, and the position of the magnet is not fixed, but continually oscillating. The extent of these oscillations, however, is exceedingly small. In fact if T be the time of vibration of the magnet from rest to rest under the action of the earth, and if t be one quarter of the time of revolution of the coil, and if δ be the deviation as read on the scale, then the same amplitude of these oscillations will be

$$c=\frac{t^2}{\mathrm{T}^2}\delta.$$

In the actual experiment $\frac{t}{\mathrm{T}}=$ about $\frac{1}{200}$ and δ less than 400 millimetres, so that the whole extent of vibration would be less than $\frac{1}{100}$ of a millimetre on the scale. This vibration was never observed and did not interfere with the distinctness of vision.

The only oscillations observed were the free oscillations of the magnet. They arose from accidental causes at the beginning of the experiment, and were subject to slight alterations in magnitude due to changes of speed of rotation, the passage of iron steamers in the Thames, &c. The time of one vibration was about 9·6 seconds, and by reading the scale at the extremities of every vibration a series of readings was obtained, the intervals between which were proximately equal.

Now since the deviation is proportional to the velocity

$$\delta=\mathrm{C}v=\mathrm{C}\frac{dx}{dt};$$

and if we take values of δ at small intervals dt and sum them, we shall get

$$\int\delta.dt=\mathrm{C}\int v\,dt=\mathrm{C}x,$$

where x is the whole distance travelled in the time.

Hence all we have to do is to observe the deviation at every oscillation, and to ascertain the whole number of revolutions during the time of observation, and the exact beginning and ending of that time. This was done in the following way.

The coil was made to revolve by means of the driving machine, and its velocity was regulated by the governor. While the required velocity was being attained, the oscillations of the magnet were reduced within convenient limits by means of a quieting bar at a distance. The quieting bar was then put in its proper place and the observation commenced.

One observer, A, took the readings of the scale as seen in the telescope, writing down the deviation at the extremity of every oscillation and thus obtaining a reading every 9·6 seconds.

Another observer, B, with a chronometer, wrote down the times of every third stroke of the bell. The times thus found were at intervals of 300 revolutions. When the observer B noted the time, the observer A made a mark on his paper, so that after the experiment the readings of deviation could be compared with the readings of the chronometer taken at the same time.

The mean time of revolution between any two times of observation could thus be found and compared with the mean deviation between the same limits of time, and any portion of an experiment accidentally vitiated could be rejected by itself.

The experiments of each day commenced with a comparison, by means of an electric balance*, between the resistance of the experimental coil and that of a German-silver coil (called "June 4").

Then a series of readings of the scale was taken to determine the undisturbed position of the magnet. The times of beginning and ending this series were noted, and called Times of 1st Zero.

Then the coil was made to revolve, and readings of deviation and of time were taken as already described, and called 1st Spin+.

Then the direction of rotation was reversed and a second set of readings obtained, and called 2nd Spin−.

Then the undisturbed position was again observed with a note of the time. This was called 2nd Zero.

Lastly, the resistance was compared again with the standard coil. This series of experiments was then repeated if there was time.

From the values of 1st zero and 2nd zero, together with the information obtained from the photographic registers at Kew, the true value of the undisturbed reading during the 1st spin and 2nd spin was obtained. The difference between this and the actual reading is the deviation δ due to the electric currents. T was got by the chronometer readings. Now let r be the resistance of the standard coil at standard temperature, R the resistance of the experimental coil during the experiment, then by the comparison of resistances we find

$$R=xv,$$

where x is the ratio observed by means of the electric balance. But we also know that $R=\frac{N}{T\delta}+$correction, where N is a known number given at p. 76. Hence r, the resistance of the standard coil, may be found in absolute measure by the formula

$$r=\frac{N}{xT\delta}+\text{a small correction};$$

the value of $xT\delta$ should therefore be nearly constant.

Thus, on June 23rd, 1863, the experiments were made as follows:—

At $12^{h}\ 15^{m}$ the resistance of the copper experimental coil was compared with that of standard coil "June 4" taken at 101, and found to be 101·26.

From $12^{h}\ 36^{m}$ to $12^{h}\ 45^{m}$ the undisturbed position of the suspended magnet was observed, and found to be 590·28 scale-divisions as the mean of all the readings.

The position of the declinometer at Kew at the same time was 7·689 of its own scale-divisions.

From $12^{h}\ 47^{m}\ 51^{s}{\cdot}5$ to $1^{h}\ 3^{m}\ 13^{s}$ the position of the magnet was again observed while the coil was revolving; 104 readings of the scale were taken, of which the mean was 930·59. This, when corrected for scale-error, gives 931·48 as the true reading. The position of the declinometer at Kew during the same time was 7·679. The resistance, measured after the experiment, was 101·28.

---

* *Vide* Report, 1862, p. 159, and present Appendix, p. 99.

The number of revolutions was 6300 during the time of observation, so that the time of 100 revolutions was $14^{s}{\cdot}464$.

By comparing the Kew apparatus with that at King's College, it appears that 1·0 of the Kew scale =19·137 of the King's College scale. The undisturbed readings at King's College were found actually to vary very nearly in this proportion to those at Kew.

Hence it is easy to find the undisturbed reading during any given experiment by comparison with the Kew numbers.

Thus, for the first experiment on June 23rd we get

Corrected undisturbed reading .... 591·54
Deflected reading .... 931·48

Deflection δ .... $= +$ 339·94
Time of 100 revolutions $=$ T .... $=$ 14·464

Product Tδ .... $=$ 4916·90
Resistance at time of experiment x ...... $=$ 101·28

Tδx .... $=$ 4979·75

Three other experiments were made on June 23rd. The result of the four experiments was as follows:—

1st experiment. Positive rotation .... T.δ.x=4979·75
2nd „ Negative .... T.δ.x .... =5071·18
3rd „ Positive .... T.δ.x=5093·35
4th „ Negative .... T.δ.x .... =5007·66
Mean Positive result .... 5036·55
Mean Negative result.................... .... =5039·42
Mean result of June 23rd.......... 5037·98
Mean result of June 19th.......... 5075·77
Mean result of June 16th.......... 5046·18

Mean of three days .... 5053·32

It will be observed that the mean results of each day are more concordant than the individual experiments made on the same day. The errors, therefore, which we have hitherto been unable to get rid of are not of a kind which would have the effect of making the result depend on the arrangements adopted on the day of experiment, but are rather such as would destroy one another in any long series of experiments.

Dividing N by the number just found, we get for the resistance called 100 provisionally,

$$106493470+61100=10655470,$$

the second term being the correction for self-induction and for scale-reading.

Since the coil of German silver, marked June 4th, was called provisionally 101, we find as the result of the experiments for the resistance of "June 4" in absolute measure

107620116 metres per second.

Knowing the absolute resistance of "June 4," we may construct coils of given resistance by known methods.

ments, and with the specific gravity used respectively by Dr. Sie
Matthiessen.

Definition.

1. Mercury unit according to Siemens's standard issued in 1864. Sp. gr. mercury assumed at 13·557 ....
2. Mercury unit according to Siemens's experiments made for 1864 standard, but assuming sp. gr. mercury at 13·595*.
3. Mercury unit according to Dr. Matthiessen's experiments. Sp. gr. mercury assumed at 13·557 ....
4. Mercury unit according to Dr. Matthiessen's experiments. Sp. gr. mercury assumed at 13·595 ....
5. Mercury unit according to one set of coils exhibited in 1862 by Dr. Siemens (Berlin) ....
6. Mercury unit according to a second set of coils exhibited in 1862 by Dr. Siemens (London) ....

Dr. Matthiessen considers No. 4 the true value, while Dr. S
ports No 1. The Committee do not desire to express any opi
subject, but only to draw attention to the great discrepancies
the apparently simple definition of the mercury unit (first propo
Davy). Even now it cannot be said that a trustworthy standa
to the definition, exists.

The Committee have little to report concerning the standar
for the measurement of currents, quantity, capacity, or electr
The drawings for a standard galvanometer and electro-dyna
been begun. An electro-dynamometer, suitable for general u
constructed by Professor W. Thomson, and experiments are
with it.

Professor Thomson has also had some fine apparatus made for
ment of electrostatic phenomena and their comparison with el
measurements; but it will be best to describe the instruments
periments have been completed.

Dr. Joule has made some preliminary experiments with the
termine the mechanical equivalent of the unit of heat by electr

Thus, although the Committee have not accomplished all tha
they feel that such progress is being made as will justify their r

They have received assurances that the British-Association s
will be readily adopted in this kingdom, in India, Australia,
They believe that it will be accepted in America and in ma
of the world.

From France no response has yet been obtained.

The Committee wish to express their sincere regret at the de
their members, Dr. Esselbach. He had made valuable experi
electromotive force of various chemical combinations, and ha
communicate them to the Committee; but their record is now

Before concluding, the Committee have to thank Mr. Charl
the efficient assistance he has afforded, both in the determi
resistance unit and in Dr. Matthiessen's researches.

---

* This is the mean of the values given by Kopp, Regnault, and Balfou
discrepancy between the two values is far greater than could be due to a
to the reference of the specific gravity to water at 0° and at maximum den

N	Matthiessen.	Varley.	German Miles.	Observations.
te	0·02243	0·01190	0·005307	Calculated from the B. A. unit.
on	0·02357	0·01251	0·005574	From an old determination by Weber.
...	0·04686	0·02486	9·01108	No measurement made; ratio between Siemens (Berlin) and Jacobi taken from Weber's 'Galvanometrie.'
s a re . nd	0·06767	0·03591	0·01655	Measurement taken from a determination in 1862 of a standard sent by Prof. Thomson; does not agree with Weber's own measurement of Siemens's units; by Weber 1 Siemens's unit $= 1{\cdot}025 \times 10^7$ metres-second.
s 1	0·07047	0·03737	0·01666	Measurement taken from three coils issued by Messrs. Siemens.
s (	0·07081	0·03757	0·01675	Measurement taken from coils exhibited in 1862 by Messrs. Siemens, Halske & Co. (well (adjusted).
s (	0·07166	0·03802	0·01695	Measurement taken from coils exhibited in 1862 by Messrs. Siemens, Halske & Co. (well adjusted).
nit	**0·0736**	**0·03905**	**0·01741**	Equal to 10,000,000 $\frac{\text{metres}}{\text{second}}$, according to experiments of Standard Committee.
	0·6822	0·3620	0·1613	From coils exhibited in 1862 (pretty well adjusted).
t	0·7187	0·3814	0·1700	From coils exhibited in 1862 (indifferently adjusted).
...	0·7675	0·4072	0·1815	From coils exhibited in 1862 (badly adjusted).
ess	1·000	0·5306	0·2365	From a coil lent by Dr. Matthiessen (of German-silver wire).
...	1·885	1·000	0·4457	From coils lent by Mr. Varley (well adjusted).
n 1	4·228	2·243	1·000	From coils exhibited in 1862 by Messrs. Siemens, Halske & Co.*

ve.

THE NEW YORK
PUBLIC LIBRARY

PPENDIX A.—*Description of a further Experimental measurement of Electrical Resistance made at King's College.* By Prof. T. C. MAXWELL and Mr. FLEEMING JENKIN, *with the assistance of* Mr. CHARLES HOCKIN.

HE method employed in these experiments has been fully described in Apndix D to the Report of 1863. In the new experiments the elements of e calculation were varied as much as possible; fresh wire was wound on e experimental coils; observations were made with velocities differing idely from one another. Fresh measurements were made of all the corctions required, and greater precautions were taken to avoid local disturbices.

n, the number of windings, was.... 313.
l, the effective length of the wire .. 311·118 metres.
the mean circumference .... 0·993987 metre.
a, the mean radius .... 0·158194 „
b, the breadth of each coil .... 0·1841 „
$2b$, the distance from centre to centre of each coil .... 0·03851 „
e, the depth of the layers .... 0·01608 „
The weight of the wire and silk.... 110 oz. 8 dwt.
$\log \sin^3 a = 1·9624955$.
D, the distance from the mirror to the scale; 2212 millims. in some experiments, 2116 millims. in others.

The following Table gives the result of the experiments, and the comrison with those of 1863.

Time of 100 evolutions, in seconds.	Values found for coil in terms of 10^7 for each experiment.	Value of B.A. unit in terms of $10^7 \frac{\text{metre}}{\text{seconds}}$, as calculated from each experiment.	Value from mean of each pair of experiments.	Percentage error from mean value.
17·54	4·7201	1·0121	0·9978	−0·22
17·58	4·5914	0·9836		
77·62	4·8848	1·0468	1·0040	+0·40
76·17	4·4871	0·9613		
53·97	4·6607	0·9985	0·9992	−0·08
54·58	4·6666	0·9998		
41·76	4·6279	0·9915	0·9925	−0·75
41·79	4·6275	0·9936		
54·07	4·6466	0·9961	0·9924	−0·76
53·78	4·6146	0·9886		
17·697	4·6108	0·9878	1·0007	+0·07
17·783	4·7313	1·0136		
17·81	4·6452	0·9952	1·0063	+0·63
17·78	4·7489	1·0174		
17·01	4·7567	1·0191	1·0043	+0·43
16·89	4·6187	1·9895		
21·35	4·6834	1·0034	1·0022	+0·22
21·38	4·6727	1·0011		
21·362	4·6526	0·9908	1·0040	+0·40
21·643	4·7134	1·0096		
11·247	4·8658	1·0424	0·9981	−0·19
16·737	4·5305	0·9707		

Probable error of R (1864)=0·1 per cent.
Probable error of R (1863)=0·24 per cent.
Difference in two values 1864 and 1863=0·16 per cent.
Probable error of two experiments=0·08 per cent.

In constructing the standard coil, in consideration of the much great range of velocities used in 1864, the 1864 mean value was allowed to ha five times the weight of the mean value obtained in 1863.

Appendix B.—*On the Electrical Permanency of Metals and Alloys.*
By A. Matthiessen, *F.R.S.*

In Appendix A of the Report of your Committee of last year, I gave results of some experiments made to test the electrical permanency of so metals and alloys. On August 5 of this year I re-tested them, and give results in the following Table, taking the conducting power of No. 15=100· as was done in last year's Report.

	May 9, 1862.	T.	June 14, 1863.	T.	Aug. 5, 1864.
1. Silver: hard-drawn	100·00	20·2	103·915	20·0	104·397
2. Silver: annealed........	100·00	20·2	99·947	20·1	100·013
3. Silver: hard-drawn	100·00	20·2	102·807	20·2	103·655
4. Silver: annealed........	100·00	20·2	100·031	20·0	100·048
5. Copper: hard-drawn	100·00	20·1	100·248	20·2	100·276
6. Copper: annealed	100·00	20·1	100·015	20·0	100·010
7. Copper: hard-drawn	100·00	20·0	100·149	19·8	100·200
8. Copper: annealed	100·00	20·0			
9. Gold: hard-drawn	100·00	20·0	100·045	20·2	100·000
10. Gold: annealed	100·00	20·0	100·062	20·0	99·960
11. Gold: hard-drawn	100·00	20·0	99·869	20·2	99·937
12. Gold: annealed	100·00	20·0	99·877	20·3	99·960
13. Platinum: hard-drawn ..	100·00	20·0	99·951	20·2	99·989
14. Platinum: hard-drawn ..	100·00	20·0	99·999	20·2	100·008
15. Gold-silver alloy: hard-drawn	100·00	20·0	100·000	20·2	100·000
16. Gold-silver alloy: hard-drawn	100·00	19·9	99·963	20·3	99·996
17. German silver: annealed.	100·00	20·3	100·162	20·0	100·135
18. German silver: annealed.	100·00	20·3	100·145	20·0	100·152
19. German silver: annealed.	100·00	..	100·217	20·2	100·193

From the above it will be seen that the following wires have not se altered in their conducting power during the space of two years:—

No.	May 9, 1862.	June 14, 1863.	August 5, 1864.	Maximum difference corresponds to.
2.	100·00	99·911	99·977	0·25
4.	100·00	99·959	99·976	0·10
6.	100·00	99·979	100·010	0·05
9.	100·00	100·117	100·072	0·30
10.	100·00	100·062	100·032	0·20
*11.	100·00	99·941	99·937	0·15
*12.	100·00	99·985	99·960	0·10
13.	100·00	100·023	100·061	0·15
14.	100·00	100·071	100·044	0·20
15.	100·00	100·000	100·000	
16·	100·00	99·963	99·996	

* Without taking into consideration the corrections due to temperature, I pla Report these two wires with those whose conducting powers had changed.

All the values have been reduced to the first observed temperature, assuming that all pure metals vary in conducting power alike with temperature. The correction made was the addition or subtraction of 0·036 for each 0°·1, which number corresponds to the correction of conducting power for temperature at 20°. No correction has been made in the cases of No. 15 and 16, for it is so small that it may be neglected, being about 0·006 for each 0°·1.

As stated in last year's Report, the differences may be considered due to temperature; for, as there explained, a difference in the temperature of the wire and the bath might well exist, and we find in most cases a difference in the conducting power corresponding to 0°·1 to 0°·2.

It is interesting to find that hard-drawn silver and copper wires become partially annealed by age, at least the increment in the conducting power would indicate such to be the case. In the case of silver, a decided increment will be observed.

No. 8, copper, annealed, has altered so much, that there can be no doubt that it was badly soldered.

With regard to the alteration observed with the German-silver wires, it may here again be stated that it is not to be assumed that all wires of this alloy will alter in like manner. An example of this has lately come to my notice. About two years ago I made a coil of the gold-silver alloy, which was compared with one of Prof. Thomson's German-silver coils; and having them still in my possession, they have now been re-compared, with the following results:—

July 8th, 1862. Resistance of Thomson's coil being 1 at 18°·4, that of the gold-silver coil was ·88445 at 18°·4.

August 6, 1864. Resistance of Thomson's coil being 1 at 18°·4, that of the gold-silver coil was ·88447 at 18°·4.

It is worthy of remark that the first comparison was made by Dr. C. Vogt, the last by Mr. C. Hockin, and with entirely different apparatus, showing that different observers with different apparatus obtain absolutely the same results when they take great care in making the observations.

The above proves that the conducting power of all specimens of German-silver wire does not alter by age. Further experiments are being made on this subject, and in the course of a year or so we shall be able to say how far German silver may be trusted for making resistance coils.

APPENDIX C.—*On the Reproduction of Electrical Standards by Chemical Means. By* A. MATTHIESSEN, *F.R.S., and* C. HOCKIN, *Fellow of St. John's College, Cambridge.*

HAVING been requested by your Committee to make some experiments with the view of discovering the best method of reproducing a unit of electrical resistance by chemical means, we have carried out the research of which we now propose to give the results.

The experiments have been made with unusual care. It is important to point out the degree of precaution that has been taken to insure trustworthy results. The care taken in these experiments may be called great care as opposed to ordinary care on the one hand and thorough care on the other. By ordinary care is meant the care usually taken in scientific research, where no extraordinary precautions are had recourse to. The sort of accuracy obtained when a unit is reproduced with ordinary care may be seen by reference to former results. For instance, in the determination of the conducting power of mercury, described in 'Phil. Trans.,' results were obtained

In constructing the sta
range of velocities used in
five times the weight of the

Appendix B.—*On the*
By

In Appendix A of the Rep
results of some experiments
metals and alloys. On Aug
results in the following Table
as was done in last year's

1. Silver: hard-drawn ....
2. Silver: annealed........
3. Silver: hard-drawn ....
4. Silver: annealed........
5. Copper: hard-drawn ....
6. Copper: annealed ......
7. Copper: hard-drawn ....
8. Copper: annealed ......
9. Gold: hard-drawn ......
10. Gold: annealed ....
11. Gold: hard-drawn ......
12. Gold: annealed ....
13. Platinum: hard-drawn ..
14. Platinum: hard-drawn ..
15. Gold-silver alloy: hard-drawn ....
16. Gold-silver alloy: hard-drawn ....
17. German silver: annealed.
18. German silver: annealed.
19. German silver: annealed.

From the above it will be
altered in their conducting pow

No.	May 9, 1862.
2.	100·00
4.	100·00
6.	100·00
9.	100·00
10.	100·00
*11.	100·00
*12.	100·00
13.	100·00
14.	100·00
15.	100·00
16·	100·00

* Without taking into considera
last year's Report these two wires wit

larged section of the block B is given in fig. 3. *a* is a
which the rod *b*, with the platinum point *d*, can be de-
in contact with the wire of the bridge. When the pres-
moved the spring *e* lifts the handle and breaks the con-
eter wire is screwed in between the metal plates *f* and *g*.
ha between the knob *h* and the handle prevented any
rent. To the top of the block was fixed a piece of brass
rve as a pointer. A lens also was fastened to the handle
a millimetre on the scale. The body of the block was of
ebonite at the top and bottom. The block ran on a tram-
scale and wire of the balance.

of the mercury cups is given at fig. 2. At the bottom of
l m n o is placed an amalgamated copper plate, and
into the cup; the plate is held down by the wooden
is kept in its place by the pin *r s*. This plug fits the
ierced with two or more holes for the terminals to pass
were propped up with wedges, when placed under the
the balance, that these might press firmly against the
cups.

R and L had a resistance of about 20 metres of the
nent. Careful measures were made of the resistance of
dge at different points in order to find if there were any
it; this was done by putting the coils R and L in their
ng the resistance of one of them by means of a short
effect of this wire was to shift the zero-point. Two
one tenth per cent., were then placed in the centre of
the reading taken; these coils were then reversed and
aken.

esistance of the circuit from the point B to B′ when the
d, z the change in the zero-point caused by the insertion
ove mentioned, and x the difference of a pair of readings,
pressed in millimetres of the wire A A′, and lengths ex-
res of the scale; then the resistance of a millimetre of
ument about the zero-point is

$$=(l+z)\cdot\frac{a-b}{a+b}\cdot\frac{2}{x};$$

two centre coils.

is expression was found for different points from one end
wire, and did not vary more than two or three tenths
error not considerable enough to affect the results obtained
nt.

e coil R was thus found. It was placed in the mercury
the cups m_1, m_2 were joined by a stout copper bar. Two
the resistance of which was known, were placed in the two
reading taken.

o of two centre coils, x the reading of scale, which was

, $R+r$ the resistance of the circuit from B′ to the point
end of the scale nearest to R, viz. A′, l the correspond-
other side of the instrument.

Then clearly

$$\frac{R+r+x}{l+1000-x}=\frac{a}{b},$$

or

$$R+r=\frac{a}{b}(l+1000-x)-x.$$

The readings are given in the following Table:—

Ratio of $\frac{a}{b}$.	Reading.	Value of $R+r$.	Value of $R+r$.
24 : 1	120·5	$20987+24l$	21215
26 : 1	186·5	$20964+26l$	21210
29 : 1	269	$20930+29l$	21205
34 : 1	375	$20875+34l$	21197
36 : 1	409	$20867+36l$	21208
37 : 1	425·25	$20841+37l$	21192
39 : 1	454·25	$20830+39l$	21201
42 : 1	493·25	$20790+42l$	21188
47 : 1	547·25	$20732+47l$	21177
55 : 1	613	$20672+55l$	21193
60 : 1	645·25	$20625+60l$	21194
68 : 1	688	$20528+68l$	21173
76 : 1	720·75	$20483+76l$	21203

Zero-point was at 516.

Resistance of half length of circuit is 21712 millimetres of wire.

All these values are within necessary errors of observation. The first few values are most to be relied on, as the values of $r+R$ depend nearly directly on $1000-r$.

So many measurements were made in order to find whether the wire tapered towards either end. The similarity of the values found for $R+r$ shows this better, perhaps, than the direct method before described.

A set of similar measurements were made with the coil L in the left-hand mercury cups, and equally good results obtained.

The galvanometer employed was one of Thomson's reflecting galvanometers, made by Messrs. Elliott Brothers. A short coil was employed. The instrument was placed in a deal box, blackened inside, with large apertures to observe through. The spot of light could thus be clearly seen, and the divisions of the scale were sufficiently illuminated to enable the observer to see immediately in which direction the spot of light moved. The instrument was sufficiently delicate to show 0·001 per cent. difference in the ratio of any two nearly equal conductors compared, corresponding to $\frac{1}{10}$ millim. on scale of bridge.

An ordinary galvanometer was also at hand to find about the place of reading on the scale.

The balance employed for weighing was by Liebrich of Giessen, and would weigh to $\frac{1}{10}$ of a milligramme with accuracy. The weights were adjusted by Oertling, and again tested by weighing them against the largest weight (50 grms.). Mr. Balfour Stewart was kind enough to test this weight, and found its value to be exactly 50·000 grms. All weighings made in this search were double weighings.

The measurements of lengths of wires tested were made with a beam- mpass. It was furnished with a vernier carrying a telescope. The in- ument was fixed horizontally before a window, the ends being clamped to elves in the wall on either side of the window.

The telescope pointed downwards, and the wires to be measured were laid a board fixed below the instrument.

With this apparatus measurements could be made with the greatest cer- inty to $\frac{1}{50}$ of a millimetre, the telescope being sufficiently powerful to ow much smaller lengths than this.

We are indebted to Mr. B. Stewart for measuring the values of the divi- ons of the instrument.

Thermometers.—Two thermometers were employed. They were made by essrs. Negretti and Zambra. One was divided to $\frac{1}{5}$ of a degree Centi- ade, the other to single degrees. The large thermometer was found to be rrect by the Kew standard. The zero-points of the thermometers were refully taken.

Trough.—The wires the resistances of which were to be determined were aced in a glass tube immersed in a trough of water.

The trough was 1·5 m. long by 0·15 m. square section. A stream of water wed through it, coming in by the tube V (fig. 1) and escaping by the waste- pe W. This arrangement was adopted because it was found that naphtha oil soon acted on the wires and altered their resistance, so that they could t be immediately exposed to the action of a liquid. The details of the rangement will be understood by reference to fig. 4.

The wire to be tested, *a b*, was soldered at its ends to copper bars, as *a c*. to each of these bars was slipped a piece of glass tubing, as *e f*. These tubes ere fastened to the copper bars by india-rubber tubing. The wire, with s connexions, was then placed in the large glass tube A B. The piece of bing *e f* was then fastened to the bent tube C E D F by india-rubber tubing.

The ends of the terminals *a c* were beaten out flat and amalgamated. e bent tubes were nearly filled with mercury, and the terminal *c* was con- cted with the mercury cups m'_1, m'_2 of the instrument by copper rods amal- mated at each end.

The resistances of the wires were compared with those of coils of German ver, well varnished, immersed in a cup of oil. The temperature of the oil s determined by the small thermometer before described.

Method of observing.—The wires were placed in the trough and the con- xions made. The water was then turned on and allowed to flow for about teen minutes. The large thermometer was placed in the trough, and the nperature was read off by means of a lens placed so as to avoid all error parallax. The small galvanometer was then connected with the electric lance, and the approximate reading found.

The large galvanometer was next connected, and the block handle pressed wn until any thermal current that existed had ceased to cause the needle the galvanometer to oscillate. The battery contact was then made for an stant with the foot. The slight kick given by the spot of light at once owed which way the block had to be moved, without its being necessary keep the battery on long enough to heat the conductors sensibly.

The observing-room was kept at a very equable temperature by a screen fore the window, also the wire of the balance was protected by a piece of arding from the heat radiating from the observer's body.

After every observation the temperature of the coil and the water in the ough was read off, and if *any* difference was observed between these read-

No. III.

Temperature of coil.	Reading of bridge-scale.	Temperature of wi
21°·6	565	20°·8
21·8	570	21
21·8	573	21
22·0	572·5	21
Length 1·6187 m.	Zero-point at 514.	Weight 2·7151 gra

Resistance of metre-gramme of wire No. I. 1·0000
" " No. II. 1·0005
" " No. III. 1·0011

GOLD.

Three gold wires were tried.

No. I. from Australian gold.
No. II. from English coin.
No. III. from English coin.

The metal was first dissolved in nitro-hydrochloric acid, the excess acid was then evaporated off, and the salt largely diluted with water precipitate the chloride of silver. After filtering the gold was precipitat by sulphurous acid, the precipitate collected in a small beaker, and was four times with hydrochloric and nitric acid alternately. After drying was fused with borax and nitrate of potassium and cast. It was again fu and finally cast in the mould.

Wire No. I.

Temperature of coil.	Reading of bridge-scale.	Temperature of wire.
20°·2	849	18°·8
20·4	849·8	18·8
20·4	851·5	18·9
20·8	852·5	18·9
Length 0·8854 m.	Zero-point at 515·2.	Weight 2·2200 gram

No. II.

21·6	634·5	20·2
21·6	638	20·3
21·6	638	20·3
21·8	638	20·3
Length 0·9998 m.	Zero-point at 515·2.	Weight 2·9021 gram

No. III.

19·8	782	19·2
20·1	788	19·4
20·5	784·6	19·6
20·8	797	19·8
Length 1·0211 m.	Zero-point at 515.	Weight 2·9753 grai

Resistance of metre-gramme of wire No. I. 1·0000
" " No. II. 0·9998
" " No. III. 0·9995

LEAD.

With lead very good [illegible] e obtained. Five wires were deter

ires were pressed at a gentle heat, the press being carefully bored and
l beforehand. As the wire came from the press it was received on a
ı board. It was then at once soldered on to the connexions and placed
trough. The solder employed was Wood's cadmium alloy. After
cut from the connexions the wire was straightened by rolling between
oards with great care; it was then placed on the board beneath the
compass, adjusted to the groove below the line of motion of the cross
of the telescope, and carefully measured and then weighed.

re No. I. was cut from a bar of commercially pure lead, prepared by
aker of Sheffield.

re No. II. made from lead obtained by heating the acetate thrice re-
llized. This specimen was kindly prepared by Mr. Mathews.

e No. III. from the acetate of lead of commerce twice crystallized.

re No. IV. from the acetate of lead of commerce three times crystallized.

re No. V. from the seventh recrystallization of acetate of lead. Kindly
red by Professor Atkinson.

Wire No. I.

mperature of coil.	Reading of bridge-scale.	Temperature of wire.
18°·1	355	17°·5
18·2	362	17·3
18·3	362	17·6
18·4	362	17·6
ngth 0·4907 m.	Zero-point at 514.	Weight 2·0689 grammes.

No. II.

16·4	855	17·1
16·4	867	17·5
18·0	869	17·6
18·1	869	17·6
ength 0·5100 m.	Zero-point at 514·5.	Weight 2·1320 grammes.

No. III.

17·0	746	16·1
17·0	748	16·2
17·2	748	16·2
17·4	748	16·3
ength 0·4910 m.	Zero-point at 516.	Weight 1·9883 gramme.

No. IV.

17·2	525	15·3
17·6	529	15·3
17·7	530	15·3
17·8	535	15·4
ength 488·2 m.	Zero-point at 515·2.	Weight 1·9991 gramme.

No. V.

18·8	628	17·8
18·8	628	17·8
19·1	634	18·0
19·6	640	18·2
ength 0·4915 m.	Zero-point at 515·5.	Weight 2·0253 grammes.

To calibrate a tube it was taken and carefully cleaned with pure nitric acid, and then with a solution of caustic potash. It was then well rinsed with distilled water, and dried by passing a current of hot air through a chloride-of-calcium bulb and then through the tube. A small column of mercury was put in the tube, and the length of column measured by the beam-compass. The column was shifted along the tube by sucking up or blowing through an india-rubber tube with a chloride-of-calcium tube inserted between it and the tube to be calibrated. By this arrangement the column could be adjusted with the greatest nicety to the place in the tube required. The lengths of the column were taken at equal intervals from one end of the tube to the other. The formula for correction used is given below.

Let C be conducting power of a tube of uniform bore and of length, capacity equal to that of tube considered; C′ observed conducting power. Then

$$C' = C\frac{n^2}{\Sigma\lambda\,\Sigma\frac{1}{\lambda}},$$

where n is the number of measurements made, λ the length of the column of mercury in any position, the summation extending to all the readings taken.

The ends of the tubes were ground by putting some emery powder and naptha on a slate table, holding the tube vertically upright with the left hand, and with the right hand rubbing the end of the tube in contact with the table round the circumference of a small circle. Thus the end of the tube was made slightly convex, the opening being at the apex of the convexity. To measure the tubes they were placed under the beam-compass, and a stout pin inserted partially into each end.

From the shape of the ends of the tube, the point where the pin emerged from the tube could be exactly seen and the measurement made with certainty. Many measurements were made turning the tube round its axis through a small angle before each measurement, and the mean of the lengths found taken for the true length. To find the weight of the tube full of mercury it was carefully cleaned, filled with mercury, and placed in a long narrow trough full of pure mercury. The tube was held down by iron weights, a thermometer inserted in the trough, and the apparatus allowed to stand until the temperature was constant. After the true temperature had been obtained the tube was taken out of the trough and the contents weighed.

This was managed in the following manner. One operator took hold of the tube by pressing a finger against each end and lifting from the trough; the little globules adhering to the outside of the tube were then rapidly removed by two assistants with brushes.

The mercury was then allowed to flow slowly out into a small porcelain crucible and weighed. In this way pretty consistent results were obtained if the tubes were cleaned before each filling.

To determine the resistance of the tubes they were placed in the water trough, with bent pieces of tubing fastened on to the ends with india-rubber tubing and reaching above the surface of the water.

The terminals were of copper, well amalgamated. They dipped into the bent tubes and came flat against the ends of the tubes the resistance of which was to be determined. In the calculation of the weight of mercury at 0° in the tube from the observed weight, Regnault's value for the expansion was used.

nnexions of amalgamated platinum were first used, but did not give results. It was found that the amalgamation was imperfect. The meradhering to the platinum was rubbed off against the ends of the tube, he resistance varied with the height of the mercury in the bent tubes. platinum was amalgamated by dipping it into a mixture of mercury odium amalgam. The sodium was then oxidized and dissolved off by ng the platinum in a little dish of water and hydrochloric acid. The nal was then drawn through a dish of clean mercury, so that the r floated off. The platinum was then for the time beautifully amalted; but the mercury soon drained off when the plate was exposed to ir, and could be easily rubbed off even when the platinum was immersed ercury.

Tube No. I.

Temperature of coil.	Reading of bridge-scale.	Temperature of wire.
18°·1	346·0	18°·2
18·4	349·2	18·6
18·4	349·2	18·8
18·8	348·0	18·0
grms.	Zero-point 515	Length 0·9365 m
temp. 19°·6 .... 24·7021		
" 21·0 ..... 24·6930		
" 20·8 .... 24·6950		
reduced to 21°:—		
24·6958		
24·6930		
24·6940		

Tube No. II.

19°·6	188·0	19°·0
19·9	186·8	19·05
20·0	186·5	19·1
20·0	186·5	19·1
grms.		Length 0·6563 m.
at 21°·2 .... 12·3140		
" 21·6 .... 12·3132		

Tube No. III.

19°·0	633·5	18°·9
19·0	633·1	18·8
19·1	631·7	18·8
19·15	631·3	18·8
grms.		Length 0·5497 m.
at 22°·2 .... 8·2894		
" 22·2 .... 8·2836		

Results.

Resistance of tube	No. I.	1·00000
„ „	No. II.	0·99849
„ „	No. III.	1·00000

An approximate table is subjoined of the resistances of a metre-gram of the different metals in terms of the B. A. unit, 1864:—

Copper	0·1469
Silver	0·1682
Gold	0·4150
Gold-silver alloy	1·668
Lead	2·257
Mercury	13·06

From the foregoing results we may draw these conclusions:—

That with great care a unit may be reproduced with great accuracy any of the metals or alloys above mentioned.

Of those tested it appears that lead is the most preferable on accoun its easy purification, and because the presence of impurities, amounting several per cent., produce no very disproportionate effect on its conduct power. For instance—

Conducting power of lead is				7·77
Of lead with	12·7	per cent. volume of	tin is	8·13
„	10·6	„ „	cadmium	8·38
„	2·3	„ „	bismuth	7·0
„	3·8	„ „	antimony	7·1
„	2·3	„ „	silver	7·9

With the other metals and alloys tested a much greater difference is fo in the conducting power when such impurity exists.

A few examples will show this.

The conducting power of pure copper is	100
Of copper with 1·6 per cent. in volume of silver	65
Of silver with 1·2 „ „ gold	59

Pure silver being taken as 100.

Of gold with 1·2 per cent. of silver	73·8

The conducting power of pure gold being 78.

If the conducting power of mercury is				10·9
That of mercury with	1·18	per cent. volume of	lead is	11·5
„	1·8	„ „	tin	11·8
„	1·8	„ „	zinc	12·4
„	0·7	„ „	gold	11·6
„	1·2	„ „	silver	11·6

The manipulation with lead is rendered easier by its high resistance.

Mercury is easily purified, and good results are always obtained it. It would, however, in reproducing a unit, be necessary to distill mercury, because traces of such impurities as silver and gold, which easily get into it when in use in a laboratory, cannot be removed by t nt with nitric acid. The chief labour is in selecting and calibrating the bes, and this is very great.

The results obtained with the gold-silver alloy, even when prepared by ferent persons, supposing great care used, give very accordant results; d for the easiness with which it can be made it may be recommended for oducing a unit.

Electrotype copper would appear a good substance. The agreement of sults obtained with commercial electrotype copper with those obtained th copper prepared from pure salts shows this.

The maximum difference of the conducting powers of electrotype copper, observed with ordinary care, is 1·6 per cent. Copper is not, however, to preferred, as great care and some practice is necessary to draw a good re.

The purification and drawing of pure gold and silver would, in the hands any one but a chemist, lead to no good results, in all probability. These ts being considered, we should prefer lead for the reproduction of a unit. doubt it would be well to use two or three substances to check the results. r these auxiliary substances mercury and the gold-silver alloy may be remmended. The choice between these two will depend on the appliances the individual observer. When thorough care is taken all the above ans are equally good.

On forming an opinion on the difficulty of reproducing a unit by chemical ans it must be remembered that if any thing like accuracy is wished for, t only expensive and delicate apparatus is required, but also very much time st be spent, and a great deal of experience in the manipulation is required. e experiments here described extended over about six months. Any rson wishing to reproduce a unit should bear these considerations in mind, ecially as it is the intention of your Committee to cause coils to be issued resenting a known resistance. That copies of a given resistance can be de to a much greater accuracy than that to be obtained by chemical or er known means of reproduction, and that coils can be compared by difent observers with different apparatus to almost any degree of accuracy though this fact has been brought into question by a former experimenter), roved by the following facts.

The two units which have come into our hands, made by Messrs. Siemens d Halske from copies of the coil used last year by your Committee for the ermination of the absolute unit, were compared against the standard coil d found to agree with it within two-hundredths per cent. Again, copies of eber's unit, one made of the gold-silver alloy, the other of German silver, re compared at the interval of two years by different observers with difent apparatus, and the results found to agree to one half a hundreth per t.

It is from the fact that copies can be produced with almost absolute curacy, with a minimum of cost and labour as compared with chemical or chanical means of reproduction, that we seem quite justified in recomnding all who wish to obtain a standard to procure a copy of the British-sociation unit, or any other in general use. As copies of the British-Assotion unit are being sold at a reasonable price by several of the leading strument makers, which, we are given to understand, will agree together ry closely, we confidently recommend the adoption of this unit.

And, in conclusion, we still adhere to the opinion, given in Appendix C of e Report of 1862, that the best means of reproducing a unit, for those o have not the opportunity of procuring a copy, and who cannot afford the time and expense necessary to reproduce the unit with great care, is to procure a given length and weight of the gold-silver alloy, such as shall have been found equal to the unit adopted (the quantity required being very nearly 0·5995 of a metre of a wire, one metre in length of which would weigh a gramme) for the British-Association unit.

FOURTH REPORT—BIRMINGHAM, SEPTEMBER 6, 1865.

MEMBERS OF THE COMMITTEE:—Professor Williamson, Professor Wheatstone, Professor W. Thomson, Professor Miller, Dr. A. Matthiessen, Mr. Fleeming Jenkin, Sir Charles Bright, Professor Maxwell, Mr. C. W. Siemens, Mr. Balfour Stewart, Dr. Joule, and Mr. C. F. Varley.

THE Committee has the pleasure of reporting that the object for which they were first appointed has now been accomplished.

The unit of electrical resistance has been chosen and determined by fresh experiments; the standards have been prepared, and copies of these standards have been made with the same care as was employed in adjusting the standards themselves; seventeen of these copies have been given away, and sixteen have been sold.

The chief work of the Committee this year has been done by Dr. A. Matthiessen. Last year's Report announced the completion of the experiments determining the resistance in absolute measure of a certain coil of German-silver wire. Taking this coil as the basis, Dr. Matthiessen, assisted by Mr. C. Hockin, prepared ten standards, each expressing the British-Association unit of electrical resistance; two of these standards are coils of platinum wire, two are of platinum-silver alloy, two are coils of wire drawn from a gold-silver alloy, two are coils of wire drawn from a platinum-iridium alloy, and the remaining two are tubes of mercury.

The wires employed in the coils are from 0·5 millim. to 0·8 millim. diameter, and range from one to two metres in length. They are insulated with white silk, and are wound round a long hollow bobbin of brass. The wires are imbedded in solid paraffin, and enclosed in a thin brass case, which allows the coils to be plunged in a bath of water by which their temperature may be conveniently regulated and observed. Two short copper terminals project from the case and are forked at their ends, so that they may be connected with the Wheatstone's balance in the manner recommended by Professor W. Thomson, avoiding the error due to the possible resistance of connexions. The mercury standards consist of two glass tubes about three-quarters of metre in length.

These ten standards are equal to one another and to the British-Assoc unit, at some temperature stated on the coil or tube, and lying between and 16°·5 C.

None of them, when correct, differ more than 0·03 per cent. from value at 15°·5 C.

In the choice of the [illegible] f which the standards are constru ommittee have been much assisted by the experiments on permanency made y Dr. Matthiessen.

Silver and copper were found to alter in their resistance simply by age. erman silver was also found to alter in some cases.

These materials had therefore to be rejected. Gold appears constant; but wing to its low specific resistance a considerable length would have been quired, unless a wire had been adopted of very small diameter. This was ot thought desirable, for several reasons: any slight decay or injury in the urface of a small wire would cause much greater alteration in the resistance an the same injury to a large wire; a small wire would be more liable to echanical injury, and would be much more rapidly heated by the passage currents. The Committee having rejected small wires for these reasons, ought it unnecessary to incur the expense of a large and thick gold wire. he great change of resistance caused by a change of temperature furnished nother reason for rejecting gold and other pure metals. One pair of andards, however, was made of platinum, which appeared the most suitable all the pure metals. Platinum and the three alloys named appear all to very constant—that is to say, their resistance is not altered by age, or en by being subjected to considerable heat and recooled.

These materials also possess considerable mechanical strength; they are ot easily injured by chemical action, they have considerable specific resistnce, and that resistance, in the case of the three alloys, changes little with change of temperature.

It is of course impossible to say with certainty that their resistance will not ry with time; but it is most unlikely that the resistance of all will vary in e same ratio. If, therefore, as is hoped, the eight coils made of such fferent materials retain their relative values, some confidence may be felt the permanence of the unit.

Some additional security is given by the power of reproducing the unit, if lost, chemical means, or by fresh experiments on absolute electro-magnetic meare, although neither of these means at present appear to give such perfect curacy as would be secured by the permanency of a material standard. Fresh solute experiments of the kind described in previous Reports would hardly reoduce the same value much within one part in a thousand; and Dr. Matthiesn, as appears from last year's Report, is not very sanguine of obtaining a better sult than this by chemical means. Thus a difference exists in Dr. Siemens's d Dr. Matthiessen's reproduction of a unit by means of mercury, as inted out in last year's Report. It is of course probab'e that differences of is kind will in time disappear; and Mr. Siemens fairly points out that the screpancy mentioned in last year's Report, between coils made from a very d and those made from a new determination of the mercury unit, affords criterion of the accuracy with which mercury can now be used as a means reproduction. Dr. Siemens was the first person who produced numerous ts of coils accurately adjusted; and although unable to recommend the loption of his unit of resistance, the Committee once more take an oppornity of expressing their sense of the high value of Dr. Siemens's researches the reproduction of units by means of mercury. Dr. Siemens is confident at a unit can be and has been reproduced by means of mercury with an curacy of 0·05 per cent.; but, meanwhile, the chief security for the peranency of the unit consists in the preservation of standards constructed in rious ways and of various materials.

The mercury tubes furnish an additional security. A molecular change ay occur in the wires, that is to say, they may become of harder or softer temper; they may be injured chemically in course of time by some action on their surface; it is just possible that the repeated passage of currents may alter them in some way, although we have no reason as yet to expect such an alteration.

Mercury is free from all these objections. Its temper cannot vary, and as it would be purified afresh on each occasion, it will be chemically uninjured.

On the other hand, some fresh dangers may occur in its use. The tubes themselves may alter in time, or the mercury may not always be absolutely pure. Absolute security cannot be had; but the choice of a variety of materials will probably prevent any serious alteration from occurring without detection.

The copies which have been issued are similar in form to the standard coils; but the terminals are simple thick copper rods, intended to be dipped in mercury cups. The security given by this mode of connexion is sufficient for all ordinary purposes, and it was feared that the use of the double terminals might not be everywhere understood. The platinum-silver alloy has been used in all the copies. Wire made of this alloy is very strong and ductile. It can, for instance, be drawn down to a diameter of 0·0002 inch. Its resistance is not permanently altered even by a great change of temperature, and even annealing hardly affects it. Moreover, the change in its resistance due to a variation of 1° Centigrade is at ordinary temperature only 0·032 per cent., being less than that of any other alloy tested. It is also a commercial alloy, which has been long used by dentists; and Dr. Matthiessen points out, as a curious coincidence, that many commercial alloys coincide with proportions indicating peculiar electrical properties. *Vide* Appendix A.

The copies of the standard have been supplied for £2 : 10*s*. in boxes, with small mercury cups for the connexion, and with a printed direction for use inside the box, stating the temperature at which that particular coil is equal to 1 B.A. unit.

A satisfactory proof of the accuracy with which these coils have been prepared was given by four independent observations, by practical electricians not belonging to the Committee, of the relative value of four distinct B.A. coils and four independent standards issued by Dr. Siemens.

These four observations gave 10456, 10455, 10456, and 10457 as the measures of Siemens's standard, in terms of the B.A. units, proving the accuracy both of Dr. Siemens's work and that of the Committee.

Twenty coils were to be distributed gratis, and seventeen have actually been given away to the following recipients:—

The Directors of Public Telegraphs in

France.
Austria.
Belgium.
Spain.
Italy.
Portugal.
Prussia.
Sweden and Norway.
Russia.
India.
Queensland.
Victoria.
New South Wales.

Also to Professor Kirchhoff, Dr. Joule, Professor Neumann, and Professor Weber.

Three remain for distribution. Sixteen have been sold. Dr. Faraday, on behalf of the Royal Institution, was the first purchaser.

In distributing the coils, it was thought best not to give them to institutions, where they would probably have laid on a shelf useless and unknown; but rather to distribute them widely, where they might become available to
al electricians.

The new unit has been actually employed to express the tests of the tlantic Telegraph Cable. Mr. Varley promises that the unit shall in future the basis of the coils used by the Electric and International Company.

Sir Charles Bright promises that the unit shall be exclusively used by the itish and Irish Magnetic Telegraph Company.

A standard has been supplied to the Royal Engineers at their request. The ad of the Telegraph Department in India has introduced the unit, and ere is little doubt that the British Colonies generally will adopt it.

More time will certainly be required to introduce it on the Continent. The ench Government has taken no steps to insure its introduction; but Blavier, the official editor of the 'Annales Télégraphiques,' has promised cordial support to the Committee. The Austrian Government has pro- sed to use the coils experimentally, and the German gentlemen to whom ls were given have promised to give their best assistance.

oils have also been bought by the managers of two large telegraphic blishments in Switzerland, at Neuchatel and Zurich. There is there- reason to hope that the unit may come into extensive use.

When standard galvanometers, Leyden jars, and electrometers are issued, forming part of one coherent and necessary system, it is probable that the unit will be found so much more useful than any other as to supplant m entirely. Until these further issues take place, it will only be adopted ier by men who can understand the advantage given by it in calculation, or electricians who feel confidence in the recommendations of your Committee.

With a view to experiments which will allow of these further issues of trical units, a large electrodynamometer has been designed and is nearly plete. Graduated Leyden jars, with air as the only dielectric, have also n designed and are nearly ready for use. An apparatus for the determi- ion of the quantity called v in Appendix C of the 1863 Report is in the e condition. Prof. W. Thomson has for some time had ready apparatus absolute measurements of electrical effects, but his connexion with the antic Cable has suspended his work. Dr. Joule promises fresh measure- nts of the mechanical coefficient of heat, and has only been delayed by want of experiments which other members of the Committee must pre- usly complete.

n conclusion, the Committee are at last able to report one positive result, they feel that much more remains to be done.

APPENDIX A.—*On the Construction of the Copies of the B.A. Unit.*

By A. MATTHIESSEN, *F.R.S., and* Mr. CHARLES HOCKIN.

E standard coil used in the experiments at King's College, described in the port of your Committee for 1864, was put into our hands about last ristmas, in order that unit-coils representing a resistance equal to ten llion metres per second in Weber's electro-magnetic system might be made m it.

Since that time several unit-coils have been made and issued.

We propose to state the method by which these coils were made, and the sons for choosing the particular alloy which has been adopted for the con- ctor. The alloy referred to is composed of 66 per cent. of silver and 33 platinum.

This alloy possesses many properties which fit it for the use to which it has n put.

As to its electrical properties:—

I. It alters less in electrical resistance with changes of temperature th any other known alloy.

The importance of this point needs hardly to be enforced on any one w has used resistance-coils.

The increment in the resistance of the alloy due to a change of tempe ture from 0° to 100° C. is only 3·2 per cent.

II. The conducting power of the alloy is very low, and is about one l that of German silver.

III. The conducting power of the alloy is not altered by baking, tha by exposing it to a temperature of about 100° C. for several days.

This is a property of great importance, for it has been observed that t conductors which do not alter by baking, do not alter by age either. experiments by which this has been established have been published former Reports.

IV. The conducting power of a wire of the alloy is little altered annealing.

Further, the alloy does not oxidize by exposure to the air; it does not rea alloy with mercury; it makes a sufficiently pliable wire, and can be draw a very great degree of fineness. Dentists have made considerable use in consequence of its good chemical and mechanical properties*. Of alloy twenty unit-coils have been made and sent to several leading ele cians at home and abroad. The form of bobbin adopted for putting up wire, and shown in Plate IV. fig. 1, has been found very convenient, as it be immersed in water during an observation. The wire is twice coated silk, and protected by being imbedded in solid paraffin.

Besides the coils already mentioned, ten unit-coils have been made, w will be deposited at the Kew Observatory.

Any one possessing a copy of the B.A. unit may have it compared at future time against one of these coils for a small payment.

Of the coils to be sent to Kew, two are of the platinum-silver two of the gold-silver alloy, two of a platinum-iridium alloy, and tw commercially pure platinum. Two mercury units have also been prepar

With so many coils for reference, made of such different metals, it ap quite improbable that the unit now proposed should be lost.

Along with the above-mentioned coils will be preserved the standard used in the experiments first referred to, the coil used in the similar ex ments made by your Committee in 1863, and several copies of these coil

Of the coil called "June 4th" in the Report of your Committee for 1863 German-silver copies have been made. Of the other coil used in 1864, German-silver, two gold-silver, and one platinum-silver copy have been n

These coils have twice been recompared together at intervals of months, and will be again compared; and if they are still found not to altered, they will be deposited at the Kew Observatory for reference, values being engraved on them.

The method adopted to obtain the unit from the standard which had certain temperature a resistance of 4·6677 B.A. units was this:—

Coils were made with the following approximate resistances, viz.:

Two coils nearly equal to $\frac{1}{2}$ unit, called $\frac{1}{2}\,a$ and $\frac{1}{2}\,b$.
" " 1 unit, " $1\,a$ " $1\,b$.
One coil " 2 units, " 2.
" " $2\frac{1}{2}$ units, " $2\frac{1}{2}$.

---

* Messrs. Johnson and Matthey inform us that this alloy has been in use for twenty years.

The electrical balance used was that described in a paper on the reproduction of a unit by chemical means, in the Report of your Committee for 1864.

With this instrument two conductors, differing in resistance by not more than 3 per cent., could be directly compared, and the ratio found depended on to 0·0025 per cent.

Numerous comparisons were made by means of this balance between the following sets of coils, viz.:—

$\frac{1}{2}a$ was compared with $\frac{1}{2}b$.
$\frac{1}{2}a+\frac{1}{2}b$ „ „ $1a$.
$1a$ „ „ $1b$.
$1a+1b$ „ „ 2.
$2+\frac{1}{2}a$ „ „ $2\frac{1}{2}$.
$2+2\frac{1}{2}$ „ „ standard.

By taking the mean of several very concordant observations, the value of the coil $1a$ was found in terms of the standard, and therefore of the unit, to a great degree of accuracy; and from this coil the first platinum-silver unit was constructed.

All the coils to be issued are recompared some weeks after they are made, and rejected if they are found to have altered in resistance by 0·01 per cent.

All the coils sent out are correct at the temperature written on them to within 0·01 per cent., and this temperature lies between 14·5 and 16·5 in all cases.

FIFTH REPORT—DUNDEE, SEPTEMBER 4, 1867.

MEMBERS OF THE COMMITTEE:—Professor Williamson, Professor Sir C. Wheatstone, Professor Sir W. Thomson, Professor Miller, Dr. A. Matthiessen, Mr. Fleeming Jenkin, Sir Charles Bright, Professor Maxwell, Mr. C. W. Siemens, Mr. Balfour Stewart, Mr. C. F. Varley, Professor G. C. Foster, Mr. Latimer Clark, Mr. D. Forbes, Mr. Charles Hockin, and Dr. Joule.

THE Committee have much pleasure in reporting that during the past year considerable progress has been made, and that the principal instruments required by the Committee for experiments have been completed and are in use.

Experiments have been conducted by Dr. Joule, having for their object the determination of the mechanical equivalent of heat, by observing the heat generated in part of a voltaic circuit, the resistance of which was measured in absolute units by means of the standard of resistance issued by the Committee.

Last year preliminary experiments of this kind had been made by Dr. Joule, and the agreement which he then reported between his mechanical equivalent obtained by frictional experiments and that obtained by the electrical method was so close as to lead to a suspicion that it was partly fortuitous.

of some submarine cable; and the rough units thus introduced are gradually creeping into use, although all electricians have been anxious that the Committee should issue a more scientific standard. Under these circumstances, Mr. Jenkin has adjusted a mica-condenser, approximately equal to 10^{-15} absolute electromagnetic units. The capacity of this condenser is assumed as that which it possesses after electrification for one minute, and is measured by the discharge through a galvanometer, in the manner usually practised when testing the charge of a submarine cable. The formula for obtaining the measurement in absolute units from the throw of the needle is very simple, requiring only observations of the time of oscillation, of a resistance in absolute measure, and of a deflection of the galvanometer-needle. All of these observations can readily be made, so that their accumulated error cannot exceed one per cent.; and for the present purpose this accuracy is sufficient, inasmuch as, when using the condenser, small variations inevitably occur, arising from the residual discharge. While, therefore, the new provisional unit of capacity has no claim to a high scientific accuracy, it will supply a practical want and introduce a unit based on the principles adopted by the Committee, in place of the random measures supplied by a knot of Persian-Gulf or Atlantic cable.

No decision has yet been arrived at whether the new unit shall be issued by the Committee or on Mr. Jenkin's own responsibility, nor has the price been fixed.

The experiments by which it has been obtained are given in an Appendix.

The practical applications of the standard of capacity are important. It will allow the capacity of submarine cables to be universally expressed in comparable figures, and may lead to improvement by the diminution of the specific inductive capacity of the insulator, precisely as the introduction of units of resistance has assisted the improvement in insulation and conductivity.

The electromagnetic capacity standard will also, by comparison with the electrostatic standard about to be made, furnish one mode of determining the constant called v in previous Reports, a number of much importance in the theory of electricity.

The next unit or standard for consideration is that of the difference of potentials or electromotive force in absolute measure, concerning which the experiments have been wholly in Sir William Thomson's hands. He reports that he has at last succeeded in constructing a series of electrometers capable of measuring differences of potential ranging from $\frac{1}{400}$ of a Daniell's cell up to 100,000 cells, and that these measurements can all be reduced to absolute units by comparison with one instrument of the series.

This class of instruments has been created by Sir William Thomson, who year by year has produced electrometers each surpassing its predecessor, both in accuracy and delicacy; but although those who have had practical experience of the admirable results obtained by these have for the last two or three years believed that the limit of excellence has been reached, Sir William Thomson has not ceased to invent better and simpler forms, until the instruments now supplied surpass every expectation of practical electricians and furnish, indeed, a new engine for electrical research.

The chief difficulties encountered have been the insulation of the Leyden jar, which has formed an essential part of all the contrivances, its maintenance at a constant potential, and the reduction to absolute measurement. In the present instrument absolutely perfect insulation is no longer required; y a new device for converting mechanical force into statical electricity constructed by Mr. Varley in 1859) Sir William Thomson is able at any ment to replenish the jar by a few turns of a handle, and, by a gauge trometer, he can insure that the same charge is constantly maintained the instrument. The difficulty of the reduction to absolute units consists the difficulty of comparing the extremely small forces produced by electro- tic attraction with the force of gravitation, and in the accurate measure- nt of the extremely small distances which separate the attracting surfaces. William Thomson reports that these difficulties have been overcome in his ion, and that he will be shortly in a position to construct and issue a ple pattern of an absolute electrometer or gauge of potential which will e as a standard for general use.

urther experiments and tests are, however, required before this can be e, as any precipitation would only injure the interests of the Committee. s right here to mention that the above experiments have been carried out ost entirely at the expense of Sir William Thomson.

he replenisher, which is founded on the principle of the electrophorus, very possibly supersede the old form of electrical machine entirely; it some analogy with the electromagnetic machines lately invented by C. W. Siemens and Professor Wheatstone, by which intense dynamic ects are evolved from the smallest initial trace of magnetism by the con- sion of mechanical force into electric currents, and was, indeed, suggested this invention to Sir William Thomson, who reinvented the plan patented Mr. Varley*.

A modification of the same contrivance will allow the comparison of ex- mely minute quantities of electricity, such, indeed, as might be accumulated a pin's head; by a series of rapid inductions a charge is accumulated on electrode of an electrometer, which may be made equal in potential to t on the pin's head, but infinitely exceeding it in quantity; the effect of s charge in the electrometer can then be observed without difficulty, and y increase or diminution in the quantity of electricity on the pin's head proof plane can be detected and the rate of loss or increase observed. e potentials to which various small bodies are charged can also be observed the same method, the advantage of which consists in the fact that the ginal charge on the body tested is undisturbed by the test, whereas by y of the older tests the charge was altered by being touched by a proof ne or by the electrode of the electrometer.

A similar plan has already been proposed by Mr. Varley and Sir William omson, with a water-dropping arrangement, but the mechanical contrivance in all ways preferable. No expense has been incurred by the Committee r these instruments or experiments.

Passing to the unit of current, the Committee regret that no experiments ve yet been made with the large absolute electrodynamometer constructed ith the funds granted by the Royal Society. Much difficulty has been perienced in finding a sufficiently solid foundation in London, and probably e instruments must be moved into the country for accurate use.

A portable electrodynamometer has been constructed which will be suit- le for distribution as a standard instrument. It can be compared with the rge absolute instrument, and can also be compared directly with the most nsitive astatic galvanometers yet made, as has been already proved by periment. These instruments cannot be distributed until further expe- nents on their constancy have been made.

---

* A similar plan was proposed by Mr. Nicholson in 1788 (*vide* Phil. Trans.).

III. *Comparison of B.A. Units to be deposited at Kew Observatory.*

By C. Hockin.

The following Table shows the value of the different copies of the B.A units that have been made for preservation at Kew:—

Material of coil.	No. of coil.	Date of observation.	Temperatures at which coil has a resistance $= 10^7 \frac{m}{s}$.	Observer.
Platinum-iridium alloy...	2	January 4, 1865	15°·5 C.	C. H.
		June 6, 1865	16·0	A. M.
		February 10, 1867	16·0	C. H.
Platinum-iridium alloy...	3	January 4, 1865	15·3	C. H.
		June 6, 1865	15·8	A. M.
		February 10, 1867	15·8	C. H.
Gold-silver alloy	10	January 5, 1865	15·6	A. M.
		February 10, 1867	15·6	C. H.
Gold-silver alloy	58	April 10, 1865	15·3	A. M.
		June 6, 1865	15·3	A. M.
		February 10, 1867	15·3	C. H.
Platinum	35	January 7, 1865	15·7	C. H.
		August 18, 1866	15·7	A. M.
		February 10, 1867	15·7	C. H.
Platinum	36	January 7, 1865	15·5	C. H.
		August 18, 1866	15·5	A. M.
		February 10, 1867	15·7	C. H.
Platinum-silver alloy ...	43	February 15, 1865	15·2	C. H.
		March 9, 1865	15·2	A. M.
		February 10, 1867	15·2	C. H.
*Mercury	I.	February 2, 1865	16·0	A. M.
		July 18, 1866	16·0	A. M.
		February 11, 1867	16·7	C. H.
Mercury......................	II.	February 3, 1865	14·8	A. M.
		August 18, 1866	14·8	A. M.
		February 11, 1866	14·8	C. H.
Mercury................	III.	February 11, 1867	17·9	C. H.

* The alteration of this coil, observed on February 11, 1867, is due, no doubt, to a de observed in the glass tube.

The tube was of lead-glass. Perhaps the strong nitric acid used to clean the t attacked the glass. A new mercury unit (No. III.) was made in consequence of t defect.

The apparent alteration in the platinum-iridium coils from the first value found, I beli to be owing to a clerical error. No alteration has been observed in them since the sec observation made by Dr. Matthiessen in June 1865.

The values given in the above Table are deduced from the German-silver coil called used in your Committee's experiments in 1864. This coil was found (by comparison w copies made, in 1864, of gold-silver, German-silver, and platinum-silver) not to have alte The coil B was also compared with the coil (June 4) used in 1863, and the ratio of two coils was found not to have altered.

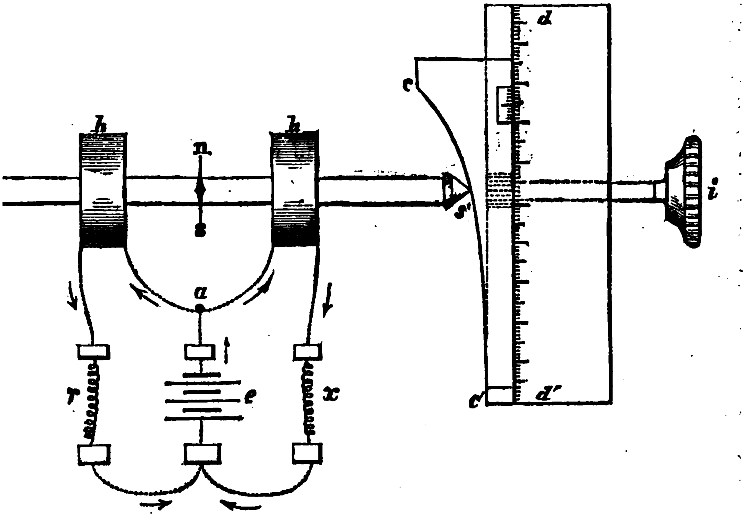
IV. *Experiments on Capacity.* *By* Fleeming Jenkin, *F.R.S.*

The capacity of a condenser made of mica and tinfoil was adjusted so approximately equal to 10^{-14} electromagnetic absolute units, accord following experiments. The capacity of any condenser can be dire

The readings to be made upon a simple lineal measure divided into equal signifying equal units of resistance.

The employment of a single and unalterable comparison-resistance.

.e apparatus constructed to fulfil these conditions is represented by the ving diagram :—



ro equal and parallel helices, h and h, are fixed upon the common $s\,s'$, which moves in the direction of its length between guide rollers. motion is effected by the end s', armed by a facing of agate, which ›s against the face of the metal curve $c\,c'$. The latter is fixed upon a moving in a groove in the rule $d\,d'$, at right angles in the direction $d\,d'$, eans of a milled head i, on the axis of which is a pinion gearing into a underneath the straight edge of the curve $c\,c'$. The rule $d\,d'$ is graduated ual parts; and opposite to the divisions is a nonius up the straight edge he curve, to divide each degree into ten parts. Whenever the milled i', therefore, is turned, the position of the curve is altered; and as the s' of the bobbin-slide is pressed against it by means of a spring, the n follows it in all its movements.

e wires of the two bobbins are connected together, in the common point th the pole of a galvanic battery e, the other pole being connected with esistances r, and through these with the remaining end of the galvano- -helices. The resistance r is made constant, and adjusted so that when the index of the curve stands exactly opposite the zero of the graduated $d\,d'$, the unknown resistance being represented by x.

is evident that, the resistance in the bobbins being equal, as also their nsions and initial magnetic effects upon the needle suspended between , if we make the resistance x equal to r, the current in the two branches e equal, and the magnet-needle therefore balanced between them only the helices are equally distant from it. Should, however, either of these ances preponderate, the strength of current in that branch will be les- ; and in order to reestablish the balance it will be necessary to shift the ns, approaching the one in which the weaker current is circulating towards spended magnet.

The instrument is erected upon a horizontal metal table standing upon three levelling-screws. The bobbin, the suspended magnet, and dial plate for observing the zero of the pointer are contained in a glass case, supported by four brass pillars. The instrument is supplied with terminals for the battery-connexions, and a current-breaker for interrupting the battery-circuit. Opposite to these are four terminal screws for receiving the ends of the resistances r and x, with contact-plugs between them, in order to quickly establish a short circuit in case the operator should be in doubt towards which side he has to move the adjusting-curve. Two constant resistances accompany the apparatus r—that which is used during the measurement, and a, a resistance of known value, which is introduced between the terminals x in order to enable the operator for his own security to make a control measurement by which he may verify the accuracy of the instrument at any time. Another purpose of this resistance is to facilitate the readjustment of the zero-point, in case the galvanometer should at any time be cleaned or a new silk-fibre put in.

In constructing the sliding curve of this instrument, it might be determined by calculation from the formula given by Weber for the deflection produced by a circular current of known magnitude upon a magnetic point, and from the given distance of the coils from each other. I prefer, however, in practice to determine the curve of each separate apparatus empirically, because it is not possible to coil a helix mathematically true, or to set it when coiled absolutely at right angles to the plane of its horizontal motion.

In the determination of each curve I use a delicately adjusted rheostat or scale of resistances in the circuit of x, giving it varying values corresponding to the equal divisions of the engraved scale, and constructing the curve according to the position which it is found necessary to give to the point s' in order to arrive at the magnetic balance. With each instrument it would be possible to have two values of r—one expressed in mercury and the other in B.A. units; and in order to measure at pleasure in either of these units, it would only be necessary to insert the one or other between the terminal screws for r.

The instrument has been found to be very convenient for the measurement of the wire-resistances of overland lines, or for the reading of resistance-thermometers; it reduces the operation and the observation of the zero position of a needle, and the reading upon a graduated scale, which can be performed by a person of ordinary intelligence without experience in electrical measurement. In accuracy and range it equals the bridge method, while as regards portability and cheapness of apparatus the advantages are decidedly in its favour [*].

II. *On a Modification of Siemens's Resistance-Measurer.*

By FLEEMING JENKIN, *F.R.S.*

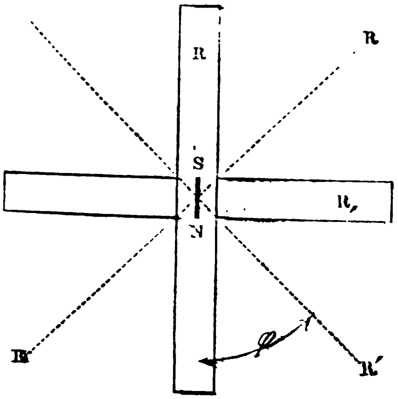
THE following method of measuring resistances was suggested to Mr. Jenkin by the above invention of Mr. Siemens:—

Let two tangent galvanometer-coils of equal magnetic moment be fixed together at right angles, with a short magnet hung in their centre, having a long light index pointing at a fiducial mark when the needle is in the magnetic meridian. Let the battery and coils be so joined that the current shall divide in the ratio of the resistances in the two coils, and shall pass in such a direction as to tend to turn the needle in opposite directions.

---

[*] I have lately constructed the same instrument on this principle with a circular instead of a straight sliding-piece, which gives the advantage of a longer graduated scale in the form of a circle. The circular sliding curve is adjusted by radial set screws in a solid ring working in a V-groove round the galvanometer.

coil with a resistance R at the beginning of the experiment stand gnetic meridian, and the other coil with a resistance R_1 in a plane



lotted lines show the position of the coils when the current is passing.

ar to the meridian; and when the current is passing in such a at R tends to turn N S in the direction of the arrow, let the coils ill the needle is again brought to the fiducial point and the coil R_1 ngle ϕ with the magnetic meridian, then we have $R = \tan\phi\, R_1$; e exerted by the coil R_1 to deflect the needle in the direction of vill then equal $m \sin\phi$; the force exerted by the coil R_1 to deflect in the opposite direction will be $m_1 \cos\phi$; and we have m sin , or $\frac{m_1}{m} = \tan\phi$, where m and m_1 are the couples experienced by under the action of the two coils; but as we have supposed these re equal magnetic moments with equal currents, $\frac{m_1}{m} = \frac{R}{R_1}$, there- $\phi\, R_1$. R and R_1 need not be the resistances of the galvano- only, but may consist of two parts, $G + r$ and $G_1 + r_1$, where re the resistances of the galvanometer-coils, but r and r_1 are ances. Thus when G G_1 and r are known, r_1 can be obtained by ervation.

be one, one hundred, or one thousand units, the resistance of r_1 al to the tangent of ϕ, or to one hundred or one thousand times t respectively minus in each case a constant $= G_1$.

ge of the instrument were not required to be very great, the coils rned by the pushing of a straight slide, equal divisions on which spond to equal increments of the tangent of ϕ, and the scale would d, so that the resistance r_1 should be read off directly, as in 's instrument.

ent coils should be made of German-silver wire, and might be practised by Helmholtz and Gaugain. Theoretically, the range rument would be infinite, *i. e.* any instrument would be capable an infinitely small or infinitely large resistance; but clearly the $G + r$ should be so arranged in each case that the angle ob- ot very different from 45°. The range of the instrument may creased by the use of ele [illegible] in the

[illegible]

[illegible] M. Ohms.

[illegible] $\times 10^{-12}$,

[illegible]

[illegible] of

[illegible] method:—

M. Ohms.

[illegible]

[illegible] insulating com-

[illegible] return,

[illegible]

M.

[illegible]

M.

[illegible] $\times 10^{-12}$,

[illegible] 16″,

ndependent series of observations divided into triplets:—

first two, 0′ 22½, 1′ 24″, last two, 9′ 37½, 10′ 39″;

oscillations in all. Mean value of $2t = 20' \, 55''$.

Talue of R_1. Direct method. Battery resistance:—

1.	223
2.	216
Mean	219

Direct deflection:—

	d.	*k.*	B.	*g.*	*n.*	R_1, Ohms.
1.	278	22000	219	47	1000	$6{\cdot}19 \times 10^9$
2.	321½	19000	219	47	1000	$6{\cdot}19 \times 10^9$

an value of R_1 in absolute units $6{\cdot}19 \times 10^{16}$. Value of $S = 99{\cdot}2 \times 10^{-12}$.

Jctober 17. *Discharge*:—

1.	2.	3.	4.	Mean.
179	180	179	180	179·5

$\sin \tfrac{1}{2} i = 91\tfrac{1}{4}$.

Times:—

0′ 55″, 1′ 56½″, 10′ 7½″, 11′ 8½″.

tal number of oscillations 30. Mean value of $2t = 20' \, 46''$.

Value of R_1. Direct method. Battery resistance:—

1.	210
2.	223
Mean	215·5

Direct deflection:—

	d.	*k.*	B.	*g.*	*n.*	R_1, Ohms.
1.	268	22000	215½	47	1000	$5{\cdot}97 \times 10^9$
2.	329	18000	215½	47	1000	$6{\cdot}01 \times 10^9$

ean value of $R_1 = 5{\cdot}99 \times 10^{19}$ absolute units. Value of $S = 99{\cdot}25$.

The seven values obtained for S give a mean value of $\cdot 9965 \times 10^{-14}$ as e capacity of the mica-plate condenser when charged for one minute, and easured by a discharge through a galvanometer, on the needle of which it ts for about 5 seconds. If we reject the two observations made on Oct. 15 which were, indeed, only preliminary, and made with less care than all the hers) we find the average to be $0{\cdot}9962 \times 10^{-14}$, and the approximation be-reen this mean and any single results is 0·42 per cent. It is therefore obable that a unit copied from this preliminary standard will not be one r cent. wrong.

A tenfold multiple (10^{-13} absolute measure) of the condenser measured is convenient magnitude as a practical unit of capacity for telegraphy; thus c capacity of the Atlantic cable per knot thus measured is 0·3535. Assum-g that the practical unit of electromotive force will be chosen as that mul-ple which is most nearly equal to Daniell's cell, *i. e.* 10^5 electromagnetic iits, then the capacity of the proposed practical unit is such that it contains ith the unit E. M. F. the same quantity of electricity as would be passed one second through a circuit of the resistance of one Megohm. Thus $)^5$ E. M. F., acting on a circuit of 10^{13}, will pass in one second 10^{-8} absolute iits of quantity; and, similarly, 10^5 E. M. F. will charge a condenser of ab-lute capacity equal to 10^{-13} with 10^{-8} absolute units of quantity. This actical series of units is that which, in the opinion of Mr. Latimer Clark id myself, is best adapted for practical use in telegraphy. Mr. Clark calls e unit of quantity thus defined (10^{-8}) one Farad, and similarly says that e unit of capacity has a capacity of one Farad, it being understood that this the *capacity when charged* with unit electromotive force (10^5).

V. *Report on Electrometers and Electrostatic Measurements.* *By* Sir Wm. Thomson, *F.R.S.*

§ 1. An electrometer is an instrument for measuring differences of electric potential between two conductors through effects of electrostatic force, and is distinguished from the galvanometer, which, of whatever species, measures differences of electric potentials through electromagnetic effects of electric currents produced by them. When an electrometer merely indicates the existence of electric potential, without measuring its amount, it is commonly called an electroscope; but the name electrometer is properly applied when greater or less degrees of difference are indicated on any scale of reckoning, if approximately constant, even during a single series of experiments. The first step towards accurate electrometry in every case is to deduce from the scale-readings numbers which shall be in simple proportion to the difference of potentials to be determined. The next and last step is to assign the corresponding values in absolute electrostatic measure. Thus, when for any electrometer the first step has been taken, it remains only to determine the single constant coefficient by which the numbers deduced from its indications as simply proportional to differences of potential must be multiplied to give differences of potential in absolute electrostatic measure. This coefficient will be called, for brevity, the absolute coefficient of the instrument in question.

§ 2. Thus, for example, the gold-leaf electrometer indicates differences of potential between the gold leaves and the solid walls enclosing the air-space in which they move. If this solid be of other than sufficiently perfect conducting material, of wood and glass, or of metal and glass, for instance, as in the instrument ordinarily made, it is quite imperfect and indefinite in its indications, and is not worthy of being even called an electroscope, as it may exhibit a divergence when the difference of potentials which the operator desires to discover is absolutely zero. It is interesting to remark that Faraday first remedied this defect by coating the interior of the glass case with tinfoil cut away to leave apertures proper and sufficient to allow indications to be seen, but not enough to cause these indications to differ sensibly from what they would be if the conducting envelope were completely closed around it; and that not till a long time after did any other naturalist, mathematician, or instrument-maker seem to have noticed the defect, or even to have unconsciously remedied it.

§ 3. Electrometers may be classified in genera and species according to the shape and kinematic relations of their parts; but as in plants and animals a perfect continuity of intermediate species has been imagined between the rudimentary plant and the most perfect animal, so in electrometers we may actually construct species having intermediate qualities continuous between the most widely different genera. But, notwithstanding, some such classification as the following is convenient with reference to the several instruments commonly in use and now to be described:—

I. Repulsion electrometers.
  - Pair of diverging straws as used by Beccaria, Volta, and others, last century.
  - Pair of diverging gold leaves (Bennet).
  - Peltier's electrometer.
  - Delmann's electrometer.
  - Old-station electrometer, described in lecture to the Royal Institution, May 1860; also in Nichol's 'Cyclopædia,' article "Electricity, Atmospheric" (edition 1860), and in Dr. Everett's

ess being chosen. If the four quadrants are in a perfectly symmetrical osition round it, and if they are kept at one electric potential by a metallic rc connecting the chief electrodes outside, the needle may be strongly lectrified without being disturbed from its position of magnetic equilibrium; ut if it is electrified, and if the external electrodes be disconnected and any ifference of potentials established between them, the needle will clearly experience a couple turning it round its vertical axis, its two ends being driven from the positive quadrants towards the negative if it is itself positively electrified. It is kept positive rather than negative in the ordinary use of the instrument, because I find that when a conductor with sharp edges or points is surrounded by another presenting everywhere a smooth surface, a much greater difference of potentials can be established between them, without producing disruptive discharge, if the points and edges are positive than if they are negative.

§ 10. The mirror (t) serves to indicate, by reflecting a ray of light from a lamp, small angular motions of the needle round the vertical axis. It is a very light, concave, silvered glass mirror, being only 8 millimetres ($\frac{1}{3}$ of an inch) in diameter, and 22 milligrammes ($\frac{1}{3}$ grain) weight. I had for many years experienced great difficulty in getting suitable mirrors for my form of mirror galvanometer; but they are now supplied in very great perfection by Mr. Becker, of Messrs. Elliott Brothers, London. The focus for parallel rays is about 50 centimetres (20 inches) from the mirror, and thus the rays of the lamp placed at a distance of 1 metre (or 40 inches) are brought to a focus at the same distance. The lamp is usually placed close behind the vertical screen a little below or above the normal line of the mirror, and the image is thrown on a graduated scale extending horizontally above or below the aperture in the screen through which the lamp sends its light. When the mirror is at its magnetic zero position the lamp is so placed that its image is, as nearly as may be, in a vertical plane with itself, and not more than an inch above or below its level; so that there is as little obliquity as possible in the reflection, and the line traversed by the image on the screen during the deflection is, as nearly as may be, straight. The distance of the lamp and screen from the mirror is adjusted so as to give as perfect an image as possible of a fine wire which is stretched vertically in the plane of the screen across the aperture through which the lamp shines on the mirror; and with Mr. Becker's mirrors I find it easy to read the horizontal motions of the dark image to an accuracy of the tenth of a millimetre. In the ordinary use of the instrument a white paper screen, printed from a copper plate, is employed, and the readings are commonly taken to about a quarter of a scale-division; but with a little practice they may, when so much accuracy is desired, be read with considerable accuracy to the tenth of a scale-division. Formerly a slit in front of the lamp was used; but the wire giving a dark line in the middle of the image of the flame is a very great improvement, first introduced by Dr. Everett, in consequence of a suggestion made by Professor P. G. Tait, in his experiments on the elasticity of solids made in the Natural-Philosophy Laboratory of Glasgow University*.

§ 11. The charge of the needle remains sensibly constant from hour to hour, and even from day to day, in virtue of the arrangement according to which it is kept in communication with sulphuric acid in the bottom of the jar, the outside of the jar being coated with tinfoil and connected with the earth, so that it is in reality a Leyden jar. The whole outside of the jar, even where not coated with tinfoil, is in the ordinary use of the instrument, especially in our moist climate, kept virtually at one potential through conduction along its surface. This potential is generally, by connecting wires or metal pieces, kept the same as that of the brass legs and framework of the instrument. To prevent disturbance in case of strongly electrified bodies being brought into the neighbourhood of the instrument, a wire is either wrapped round the jar from top to bottom, or a cage or network of wire, or any convenient metal case, is placed round it; but this ought to be easily removed or opened at any time to admit of the interior being seen. When the instrument is left to itself from day to day in ordinary use, the needle, connected with the inner coating of the jar as just described, loses, of course, unless replenished, something of its charge; but not in general more than ½ per cent. per day when the jar is of flint glass made in Glasgow. On trying similar jars of green glass I found that they lost their charge more rapidly per hour than the white glass jars per month. I have occasionally, but very rarely, found white glass jars to be as defective as those green ones; and it is possible that the defect I found in the green jars was an accident to the jars tested, and not an essential property of that kind of glass.

---

* A Drummond light placed about 70 centimetres from the mirror gives an image, on a screen about 3 metres distance, brilliant enough for lecture-illustrations, and with sufficient definition to allow accurate readings of the positions on a scale marked by the image of a fine vertical wire in front of the light.

§ 12. I have recently made the very useful addition of a replenisher to restore electricity to the jar from time to time when required. It consists of (1) a turning vertical shaft of vulcanite bearing two metal pieces called carriers (*b*, *b*, figs. 17 & 18, Plate V.); (2) two springs (*d*, *d*, figs. 16 & 18), connected by a metallic arc, making contact on the carriers once every half turn of the shaft, and therefore called connectors; and (3) two inductors (*a*, *a*) with receiving springs (*c*, *c*) attached to them, which make contact on the carriers once every half turn, shortly before the connecting contacts are made. The inductors (*a*, *a*, figs. 16 & 18) are pieces of sheet metal bent into circular cylindrical shapes of about 120° each; they are placed so as to deviate in the manner shown in the drawing from parts of a cylindrical surface coaxal with the turning-shaft, leaving gaps of about 60° on each side. The diameter of this cylindrical surface is about 15 millimetres (about ½ an inch). The carriers (*b*, *b*, figs. 17 & 18) are also of sheet metal bent to cylindrical surfaces, but not exactly circular cylinders, and are so placed on the bearing vulcanite shaft that each is rubbed by the contact springs over a very short space, about 1 millimetre beyond its foremost edge, when turned in the proper direction for replenishing. The receiving springs (*c*, *c*, figs. 17 & 18) make their contacts with each carrier immediately after it has got fairly under cover, as it were, of the inductor. Each carrier subtends an angle of about 60° at the axis of the turning-shaft. The connecting contacts are completed just before the carriers commence emerging from being under cover of the inductors. The carriers may be said to be under cover of the inductors when they are within an angle of 120° on each side of the axis subtended by the inductors. One of the inductors is in metallic communication with the outside coating of the jar, the other with the inside. Figs. 16, 17, & 18 illustrate sufficiently the shape of carriers and the succession of the contacts. The arrow-head indicates the direction to turn for replenishing. When it is desired to diminish the charge, the replenisher is turned backwards. A small charge having been given to the jar from an independent source, the replenisher when turned forwards increases the difference of potentials between the two inductors and the two coatings of the jar connected with them by a constant ntage per half turn, unless it is raised to so high a degree as to break down the air-insulation by disruptive discharge. The electric action is explained simply thus:—The carriers, when connected by the connecting springs, receive opposite charges of induction, of which they deposit large proportions the next time they touch the receiving springs. Thus, for example, if the jar be charged positively, the carrier emerging from the inductor connected with the inner coating carries a negative charge round to the receiving spring connected with the outside coating, while the other carrier, emerging from the inductor connected with the outside coating, carries a positive charge round to the receiving spring connected with the inside coating. If the carriers are not sufficiently well under cover of the inductors during both the receiving contacts and the connecting contacts to render the charges which they acquire by induction during the connecting contacts greater than that which they carry away with them from the receiving contacts, the rotation, even in the proper direction for replenishing, does not increase, but, on the contrary, diminishes the charge of the jar. The deviations of the inductors from the circular cylinder referred to above have been adopted to give greater security against this failure. A steel pivot fixed to the top of the vulcanite shaft, and passing through the main cover, carries a small milled head (y, fig. 1) above, on the outside, which is spun rapidly round in either direction by pressing the finger on it; and thus in less than a minute a small charge in the jar may be doubled. The diminution of the charge, when the instrument is left to itself for twenty-four hours, is sometimes imperceptible; but when any loss is discovered to have taken place, even if to the extent of 10 per cent., a few moments' use of the replenisher suffices to restore it, and to adjust it with minute accuracy to the required degree by aid of the gauge to be described presently. The principle of the "replenisher" is identical with that of the "doubler" of Bennet. In the essentials of its construction it is the same as Varley's improved form of Nicholson's "revolving doubler."

§ 13. The gauge consists of an electrometer of Class III. The movable attracted disk is a square portion of a piece of very thin sheet aluminium of the shape shown at α in fig. 4. It is supported on a stretched platinum wire passing through two holes in the sheet and over a very small projecting ridge of bent sheet aluminium placed in the manner shown in the magnified drawing, fig. 3. The ends of this wire are passed through holes in curved springs, shown in fig. 4, and are bent round them so as to give a secure attachment without solder and without touching the straight stretched part of the wire. The ends of the platinum wire (β, β) are attached by cement to the springs, merely to prevent them from becoming loose, care being taken that the cement does not prevent metallic contact between some part of the aluminium wire and one or both of the brass springs. I have constantly found fine platinum wire rendered brittle by ordinary solder applied to it. The use of these springs is to keep the platinum wire stretched, with an approximately constant tension, from year to year and at various temperatures. Their fixed ends are attached to round pins, which are held with their axes in a line with the fibre by friction, in bearings forming parts of two adjustable brass pieces (γ, γ) indicated in fig. 4; these pieces are adjusted once for all to stretch the wire with sufficient force, and to keep the square attracted disk in its proper position. The round pins bearing the stretching-springs are turned through very small angles by pressing on the projecting springs with the finger. They are set so as to give a proper amount of torsion tending to tilt the attracted disk (α) upwards, and the long end of the aluminium lever (δ), of which it forms a part, downwards. The downward motion of the long end is limited by a properly placed stop. Another stop (e) above limits the upward motion, which takes place under the influence of electrification in the use of the instrument. A very fine opaque black hair (that of a small black-and-tan terrier I have found much superior to any hitherto tried) is stretched across the forked portion of the sheet aluminium in which the long arm of the lever terminates. Looked at horizontally from the outside of the instrument it is seen, as shown in fig. 7, Plate V., against a white background, marked with two very fine black circles. These sight-plates in the instruments, as now made by Mr. White, are of the same material as the ordinary enamel watch-dials with black figures on a white ground. The white space between the two circles should be a very little less than the breadth of the hair. The sight-plate is set to be as near the hair as it can be without impeding its motion in any part of its range; and it is slightly convex forwards, and is so placed that the hair is nearer to it when in the middle between the black circles than when in any other part of its range. It is thus made very easy, even without optical aid, to avoid any considerable error of parallax in estimating the position of the hair relatively to the two black circles. By a simple plano-convex lens (ϕ, fig. 2), with the convex side turned inwards, it is easy, in the ordinary use of the instrument, to distinguish a motion up or down of the hair amounting to $\frac{1}{5000}$ of an inch. With a little care I have ascertained, Dr. Joule assisting, that a motion of no more than $\frac{1}{50,000}$ of an inch from one definite central position can be securely tested without the aid of other magnifying-power than that given by the simple lens. The lens during use is in a fixed position relatively to the framework bearing the needle, but it may be drawn out or pushed in to suit the focus of each observer. To give great magnification, it ought to be drawn out so far that the hair and sight-plate behind may be but little nearer to the lens than its principal focus, and the observer's eye ought to be at a very considerable distance from the instrument, no less than 20 centimetres (8 inches), to get a good magnification; and a short-sighted person should use his ordinary concave eye-lens close to his eye. The reason for turning the convexity of the small plano-convex lens inwards is, that if the eye of the observer is too high or too low, the hair seems to him curved upwards or downwards, and he is thus guided to keep his eye on a level sufficiently constant to do away with all sensible effects of parallax on the position of the hair relatively to the black circles. The framework carrying the stretched platinum wire and movable attracted disk is above the brass roof of the lantern, in which a square aperture is cut to allow the square portion constituting the short arm of the aluminium balance to be attracted downwards by the fixed attracting disk (§ 7), to be presently described. A side view of the attracting plate, the brass roof of the lantern, the aluminium balance, the sight-plate, the hair, and the plano-convex lens is shown in section (fig. 2), also a glass upper roof to protect the gauge and the interior of the instrument below from dust and disturbance by currents of air, to which, without this upper roof, it would be exposed, through the small vacant space round the movable aluminium square. The fixed attracting disk is borne by a vertical screw screwing into the upper brass mounting (z, fig. 2) (§ 7), connected with the inner coating of the Leyden jar through the guard tubes, &c., and is secured in any position by the "jam nut," shown in the drawings at z, fig. 2. This disk (s) is circular, and about 38 millimetres ($1\frac{1}{2}$ inch) diameter, and it is placed horizontally with its centre under the centre of the square aperture in the roof of the lantern. Its distance from the lower [illegible] magnetic directing-force [illegible] diminished [illegible] atmospheric [illegible] more powerful magnetic [illegible] most recent instruments [illegible] it is to be remarked that [illegible] magnets cannot be [illegible] disturbances produced by [illegible] instrument. In laboratories [illegible] being performed in the immediate [illegible] stories, where there is constant disturbance [illegible] the artificial magnetic field of the [illegible] long. To allow this, and yet have [illegible] the suspended magnetic needle [illegible] is now reduced to two small pieces [illegible] of an inch) long. For a meteorological [illegible] that the directing magnetic force should [illegible] disturbance experienced in magnetic [illegible] luminous image‡.

§ 15. The sensibility of the gauge should [illegible] the change of the jar, producing [illegible] the [illegible]

---

* That is to say, the number of scale divisions [illegible] when the chief electrodes are disconnected from [illegible] and put in metallic connexion with the two plates of a Daniell's battery.

† See Royal Institution Lecture, May [illegible] Encyclopædia,' article "Electricity, Atmospheric" [illegible]

‡ All embarrassment from this source will be [illegible] adopted (*vide* footnote to § 8).

tion of the hair, shall produce no sensible change in the deflection of the luminous image produced by the greatest difference of potentials between the quadrants, which is to be measured in the use of the instrument. I believe the instruments already made, when adjusted to fulfil these conditions, may be trusted to measure the difference of potentials produced by a single cell of Daniell's to an accuracy of a quarter per cent. It must be remembered that the constancy of value of the unit of each instrument depends not only on the constancy of the potential indicated by the gauge, but also on the constancy of the force in the field traversed by the suspended needle. As both these may be expected to decrease gradually from year to year (although very slowly after the first few hours or weeks), rigorous methods must be adopted to take such variations into account, if the instrument is to be trusted to as giving accurately comparable indications at all times. The only method hitherto provided for this most important object consists in the observation of the deflection produced by a measured motion of one of the quadrants by the micrometer-screw (*i*) when the four quadrants are put in metallic communication with one another through the principal electrodes—the force producing this deflection when the potential of the jar is constant; and therefore, the jar being brought to one constant potential by aid of the gauge, the amount of the deflection will show whether or not the force of the magnetic field has changed, and will render it easy at any time to adjust the strength of the magnets, if necessary, to secure this constancy. But to attain this object by these means, the three quadrants not moved by the micrometer-screw must be clamped by their fixing-screws so that they may be always in the same position.

§ 16. The absolute constancy of the gauge cannot be altogether relied upon. It certainly changes to a sensible degree with temperature, and to very different degrees, and even in different directions, as will be seen (§ 32) in connexion with the description of the portable electrometer to be given later. But this temperature variation does not amount in ordinary cases probably to as much as one per cent.; and it is probable that after a year or two any further secular variation of the platinum torsion spring will be quite insensible. It is to be remarked, however, that secular experiments on the elasticity of metals are wanting, and ought at least to be commenced in our generation. In the mean time it will be desirable, both on account of the temperature variation and of the possible secular variation in the couple of torsion, to check the gauge by accurate measurements of the time of oscillation of the needle with its appurtenances. The moment of inertia of this rigid body, except in so far as it may be influenced by oxidation of the metal, of which I have as yet discovered no signs, may be regarded as constant; and therefore the amount of the directing couple due to the magnets may be determined with great accuracy by finding the period of an oscillation when the four quadrants are put in connexion through the charging rod with the metal mounting bearing the guard plates, &c. I have not as yet put into practice any of the obvious methods, founded on the general principle of coincidences used in pendulum observations, for determining the period of the oscillation; but although not more than twenty or thirty oscillations can be counted, it seems certain that with a little trouble the period of one of them may be determined without much trouble to an accuracy of about $\frac{1}{10}$ per cent.

Absolute Electrometer.

§ 17. The absolute electrometer (fig. 11, Plate VI.) and the other instruments of Class III, are founded on a method of experimenting introduced by

Sir Wm. Snow Harris, and described in his first paper "On the Elementary Laws of Electricity"[*] thirty-four years ago. In these experiments a conductor, hung from one arm of a balance and kept in metallic communication with the earth, is attracted by a fixed insulated conductor, which is electrified, and, for the sake of keeping its electric potential constant, is connected with the inner coating of a Leyden battery. The first result which he announced is, that, when other circumstances remain the same, the attraction varies with the square of the quantity of electricity with which the insulated body is charged; but "it is readily seen that, in the case of Mr. Harris's experiments, it will be so slight on the unopposed portions that it could not be perceived without experiments of a very refined nature, such as might be made by the proof plane of Coulomb, which is, in fact, with a slight modification, the instrument employed by Mr. Faraday in the investigation. Now to the degree of approximation to which the intensity on the unopposed parts may be neglected, the laws observed by Mr. Harris when the opposed surfaces are plane may be readily deduced from the mathematical theory. Thus let v be the potential in the interior of A, the charged body, a quantity which will depend solely on the state of the interior coating of the battery with which, in Mr. Harris's experiments, A is connected, and will therefore be sensibly constant for different positions of A relative to the uninsulated opposed body B. Let a be the distance between the plane opposed faces of A and B, and let S be the area of the opposed parts of these faces, which will in general be the area of the smaller, if they be unequal. When the distance a is so small that we may entirely neglect the intensity on all the unopposed parts of the bodies, it is readily shown, from the mathematical theory, that (since the difference of the potentials at the surfaces of A and B is v) the intensity of the electricity produced by induction at any point of the portion of the surface of B which is opposed to A is $\frac{v}{4\pi a}$, the intensity at any point which is not so situated being insensible. Hence the attraction on any small element ω, of the portion S of the surface of B, will be in a direction perpendicular to the plane and equal to $2\pi\left(\frac{v}{4\pi a}\right)^2$[†]. Hence the whole attraction on B is

$$\frac{v^2 S}{8\pi a^2}.$$

"This formula expresses all the laws stated by Mr. Harris as results of his experiments in the case when the opposed surfaces are plane"[‡].

§ 18. After many trials to make an absolute electrometer founded on the repulsion between two electrified spherical conductors for which I had given a convenient mathematical formula in § 4 of the paper just quoted, it occurred to me to take advantage of the fact noticed by Harris, but easily seen as an immediate consequence of Green's mathematical theory, that the mutual attraction between two conductors used as in his experiments is but little influenced by the form of the unopposed parts; and in 1853, in a paper "On transient Electric Currents"[§], I described a method for measuring differences of electric potential in absolute electrostatic measure founded on that idea. The "absolute electrometer" which I exhibited to the British Association at its Glasgow Meeting in 1855 was constructed for the purpose of putting these methods in practice. This instrument consists of a plane metal disk insulated in a fixed horizontal position, with a somewhat smaller fixed metal disk hung centrally over it from one end of the beam of a balance. In two papers entitled "Measurement of Electostatic Force produced by a Battery" and "Measurement of the Electromotive Force required to produce a spark in Air between parallel metal plates at different distances," published in the Proceedings of the Royal Society* for February 1860, I described applications of this electrometer, in which, for the first time, I believe, absolute electrostatic measurements were made. The calculations of differences of potentials in absolute measure were made according to the formula quoted above (§ 17) from my old paper on "The Elementary Laws of Statical Electricity."

---

[*] Philosophical Transactions, 1834.

[†] See Mathematical Journal, vol. iii. p. 275.

[‡] "On the Elementary Laws of Statical Electricity," Cambridge and Dublin Mathematical Journal, 1846; and Phil. Mag. July 1854.

[§] Phil. Mag. June 1853.

§ 19. This formula is rigorous only if the distance between the disks is infinitely small in comparison with their diameters; and therefore, in my earliest attempt to make absolute electrostatic measurements, I used very small distances. I found great difficulty in securing that the distance should be nearly enough equal between different parts of the plates, and in measuring its absolute amount with sufficient accuracy; and found besides serious inconveniences in respect of sensibility and electric range: later I made a great improvement in the instrument by making only a small central area of one of the disks movable. Thus the electric part of the instrument becomes two large parallel plates with a circular aperture in one of them, nearly filled up by a light circular disk supported properly to admit of its electrical attraction towards the other being accurately measured in absolute units of force. The disk and the perforated plate surrounding it will be called, for brevity, the disk and the guard-plate. The faces of these two next the other plate must be as nearly as possible in one plane when the disk is precisely in the position for measuring its electric force, which, for brevity, will be called its sighted position. The space between the disk and the inner edge of its guard-ring must be a very small part of the diameter of the aperture, and must be very small in comparison with the distance between the plates; but the diameter of the disk may be greater than, equal to, or less than the distance between the plates.

§ 20. Mathematical theory shows that the electric attraction experienced by the disk is the same as that experienced by a certain part of one of two infinite planes at the same distance, with the same difference of electric potentials, this area being very approximately the mean between the area of the aperture and the area of the disk, and that the approximation is very good, even although the distance between the plates be as much as a fourth or fifth, and the diameter of the disk as much as three fourths of the diameter of the smaller of the two plates. This conclusion will be readily assented to when we consider that† the resultant electric force at any point in the air between the two plates is equal numerically to the rate of conduction of heat per unit area across the corresponding space in the following thermal analogue. Let a solid of uniform thermal conductivity replace all the air between and round the plates; and in place of the plates let there be hollow spaces in this solid. Let these hollow spaces be kept at two uniform temperatures, differing by a number of degrees equal numerically to the difference of potentials in the electric system, the space corresponding to the disk and guard-ring being at one temperature, and that corresponding to the opposite plate at the other temperature; and let the thermal conductivity of the solid be unity. If we attempt to draw the isothermal surfaces between the hollow corresponding to the continuous plate on the one side, and that corresponding to the disk and guard-ring on the other side, we see immediately that they must be very nearly plane from very near the disk all the way across to the corresponding central portion of the opposite plate, but that there will be a convexity towards the annular space between the disk and guard-ring.

---

* Phil. Mag. September and October 1860.

† "On the Uniform Conduction of Heat through Solid Bodies, and its connexion the Mathematical Theory of Electricity," Cambridge Mathematical Journal, Feb. and Phil. Mag. July 1854.

§ 21. Thus we see that the resultant electric force will, to a very close approximation, be equal to $\frac{V}{D}$ for all points of the air between the plates at distances from the outer bounding edges exceeding two or three times the distance between the plates, and at distances from the interstice between the guard-ring and disk any less than the breadth of this interstice. Hence if ρ denote the electric density of any point of the plate or disk far enough from the edges, we have

$$\rho=\frac{V}{4\pi D}.$$

But the outward force experienced by the surface of the electrified conductor per unit of area at any point is $2\pi\rho^2$; and therefore if F denote the force experienced by any area A of the fixed plate, any part of which comes near its edge, we have

$$F=\frac{V^2A}{8\pi D^2},$$

which will clearly be equal to the attraction experienced by the movable disk, if A be the mean area defined above. This gives $V=D\sqrt{\frac{8\pi F}{A}}$, the formula by which difference of potentials in absolute electrostatic measure is calculated from the result of a measurement of the force F, which, it must be remembered, is to be expressed in kinetic units. Thus if W be the mass in grammes to which the weight is equal, we have

$$F=gW,$$

where g is the force of gravity in centimetres per second.

The difficulty which, in first applying this method about twelve years ago, I found in measuring accurately the distance D between the plates and in avoiding error from their not being rigorously parallel, I now elude by measuring only *differences* of distance, and deducing the desired results from the difference of the corresponding differences of potentials. Thus let V′ be the difference of potentials between the plates required to give the same force F; when the difference of potentials is V′ instead of V, we have

$$V'-V=(D'-D)\sqrt{\frac{8\pi F}{A}}.$$

§ 22. The plan of proceeding which I now use is as follows:—Each plate (fig. 11, Plate VI.) is insulated; one of them, the continuous one, for instance, is kept at a potential differing from the earth by a fixed amount tested by aid a separate idiostatic* electrometer; the other plate (the guard-ring and wable disk in metallic communication with one another) is alternately nnected with the earth and with the body whose potential is to be

---

[*] See § 40 below.

measured. The lower plate is moved up or down by a micrometer-screw until the movable disk balances in a definite position, indicated by the hair (with background of white with black dots) seen through a lens, as shown in fig. 11. Before and after commencing each series of electrical experiments, the amount of weight to be placed on the upperside of the disk to bring the hair to its sighted position when there is no electric force is determined. This last condition is secured by putting the two plates in metallic communication with one another. For the electric experiments the weight is removed, so that when the hair is in the sighted position the electric attraction on the movable disk is equal to the force of gravity on the weight. The electric connexions suitable in using this instrument for determining in absolute electrostatic measure the difference of potentials maintained by a galvanic battery between its two electrodes are indicated in fig. 11. No details as to the case for preventing disturbance by currents of air, and for maintaining a dry atmosphere, by aid of pumice impregnated with strong sulphuric acid, are shown, because they are by no means convenient in the instrument at present in use, which has undergone so many transformations that scarcely any part of the original structure remains. I hope soon to construct a compact instrument convenient for general use. The amount of force which is constant in each series of experiments may be varied from one series to another by changing the position of a small wire rider on the lever from which the movable disk is hung.

The electric system here described is heterostatic (§ 40 below), there being an independent electrification besides that whose difference of potential is to be measured.

PORTABLE ELECTROMETER.

§ 23. In the ordinary use of the portable electrometer (figs. 8, 9, & 10, Plate VI.), the electric system is heterostatic and quite similar to that of the absolute electrometer, when used in the manner described above in § 22. But the balance is not adapted for absolute measure of the amount of force of attraction experienced by the movable disk; on the contrary, it is precisely the same as that described for the gauge of the quadrant electrometer in § 13 above, only turned upside down. Thus, in the portable instrument, the square disk (*f*) forming part of the lever of thin sheet aluminium is attracted *upwards* by a solid circular disk of sheet brass (*g*), thick enough for stiffness. Every part of the aluminium lever except this square portion is protected from electric attraction by a fixed brass plate (*h h*) with a square hole in it, as nearly as may be stopped by the square part of the sheet aluminium destined to experience the electric attraction, all other parts of the aluminium balance-lever being below this guard-plate. The aluminium lever (*i k*), as shown in figs. 8 & 10, is shaped so that when the hair (*l*) at the long end of its lever is in its sighted position, the upper surfaces of the fixed guard-plate (*h*) and movable aluminium square (*f*) are as nearly as may be in one plane. The mode of suspension is precisely the same as that described (§ 13) for the gauge of the quadrant electrometer. In the portable instrument, careful attention is given by the maker to balance the aluminium lever by adding to it small masses of shellac or other convenient substance, so that its centre of gravity may be in the line of its platinum-wire axis, or, more properly speaking, in such a position that the instrument shall give, when electrified, the same "earth-readings" when held in any positions, either upright, or inclined, or inverted (§ 30 below). Thus the condition of equilibrium of the balance, when the hair is in its sighted position, is that the moment of electric attraction round the axis of suspension shall be equal to the moment of the couple of torsion, the latter being as constant as the properties of the matter concerned (platinum wire, brass stretching-springs, &c.) will allow.

§ 24. The guard-plate carrying, by the platinum-wire suspension, the aluminium balance, is attached to the bottom of a small glass Leyden jar (*m m*); and is in permanent metallic communication with its inside coating of tinfoil. The outside tinfoil coating of this jar is in permanent metallic communication with the outside brass-protecting case. The upper open mouth of this case is closed by a lid or roof, which bears on its underside a firm frame projecting downwards. This frame has two V notches, in which a stout brass tube (*o*) slides, kept in the Vs by a properly placed spring (*p*) giving it freedom to slide up and down in one definite line*. Firmly fixed in the upper end of this tube is a nut (*a*, fig. 8), which is caused to move up and down by a micrometer-screw. The lower end of the shaft of this screw has attached to it a convex piece of polished steel (*b*, fig. 8), which is pressed upon a horizontal agate plate rigidly attached to the framework above mentioned by a stiff brass piece projecting into the interior of the brass tube through a slot long enough to allow the requisite range of motion. This arrangement will be readily understood from the accompanying drawings. It has been designed upon obvious geometrical principles, which have been hitherto neglected, so far as I know, in all micrometer-screw mechanisms, whether for astronomical instruments or other purposes. The screw-shaft is turned by a milled head, fixed to it at its top outside the roof of the instrument, and the angles through which it is turned are read on a circle divided into 100 equal parts of the circumference (or $3^\circ{\cdot}6$ each) from a fixed mark on the roof of the instrument. The hole in the roof through which the screw-shaft passes is wide enough to allow the shaft to turn without touching it, and the lower edge of the graduated circle turning with the screw is everywhere very near the upperside of the roof, but must not touch it at any point. A second nut (*c*, fig. 8) above the effective nut fits easily, but somewhat accurately, in the hollow brass tube, but is prevented from turning round in the tube by a proper projection and slot. Thus the screw is rendered sufficiently steady, with reference to the sliding-tube; that is to say, it is prevented from any but excessively small rotations round axis perpendicular to the length of the screw-shaft; and when the nut is kept from being turned round its proper axis, it forms along with the sliding-tube virtually a rigid body. A carefully arranged spiral spring presses the two nuts asunder, and so causes the upperside of the thread of the screw-shaft always to press against the underside of the thread of the effective nut, thus doing away with what is technically called in mechanics "lost time." In turning the micrometer-screw, the operator presses its head gently downwards with his finger, to secure that its lower end bears firmly upon the agate plate. It would be the reverse of an improvement to introduce a spring attached to the roof of the instrument outside to press the screw-head downwards, inasmuch as however smooth the top of the screw-shaft might be made, and however smooth the spring pressing it down, there would still be a very injurious friction impeding the proper settlement of the sliding-tube into its Vs. A stiff fork (*q*) stretching over the graduated circle is firmly attached to the roof outside, to prevent the screw from being lifted up by more than a very small space, perhaps not more than $\frac{1}{20}$ of an inch at most. In using the instrument, the observer should occasionally pull up the screw-head and press it down again, and give it small horizontal motions, to make sure that when he is using it it is pressed in properly to its Vs and down upon the agate plate. A long arm (*d*, figs. 8 and 9) (or two arms one above the other), firmly attached to the sliding-tube, carries a pointer which moves up and down with it. Two fixed guiding-cheeks on each side of this pointer prevent the tube from being carried round too far in either direction when the screw is turned: one of these cheeks is graduated so that each division is equal in length to the step of the micrometer-screw; this enables the operator to ascertain the number of times he has turned the screw. These two cheeks must never simultaneously press upon the sliding-pointer; on the contrary, they must leave it a slight amount of lateral freedom to move. If this does not amount to ·36 of a degree, the amount of "lost time" produced by it will not exceed $\frac{1}{10}$ of a division of the micrometer-circle, and will not produce any sensible error in the use of the instrument. A glass rod cemented to the lower end of the tube prolongs its axis downwards, and bears the continuous attracting-plate of the electrometer at its lower end.

---

* In consequence of suggestions by Mr. Jenkin, it is probable that the spring may be done away with, and the Vs replaced by rings approximately fitting round the tube, but leaving it quite free to fall down by its own weight. In consequence of the symmetrical position of the convex end of the screw over the centre of the attracted disk, slight lateral motions of the tube produce no sensible effect on the electric attraction.

The object aimed at in the mechanism just described is to prevent the nut and other parts rigidly connected with it from any other motion than parallel to one definite line, and to leave it freedom to move in this line, unimpeded by any other friction than that which is indispensable in the arrangement for keeping the sliding-tube in its Vs.

§ 25. If the inner tinfoil covering of the Leyden jar were completed up to the guard-plate bearing the aluminium balance, the long arm of this lever being in the interior of a hollow conductor would experience no electric influence and no force from the electrification of the Leyden jar, or from separate electrification of the upper attracting-plate, or, more strictly speaking, the electric density and consequent electric force on the long arm of the lever would be absolutely insensible to the most refined test we could apply, because of the smallness of the gap between the movable aluminium square and the boundary of the square aperture in the guard-plate. But to see the hair on the long end of the lever, and the white background with black dots behind it, a good portion of the glass under the guard-plate must be cleared of tinfoil outside and inside. Thus the electric potential of the inner coating of the Leyden jar will not be continued quite uniformly over the inner surface of the bared portion of the glass, and a disturbance affecting chiefly the most sensitive part of the lever will be introduced. To diminish this as much as possible without inconveniently impeding vision, a double screen of thin wire fences, in metallic communication with the inner tinfoil coating and the guard-plate, is introduced between the end of the lever and the glass through which it is observed.

§ 26. A very light spiral spring (*r*) connects the upper attracting-plate with a brass piece supported upon a fixed vertical glass column projecting downwards from the roof of the instrument. This brass piece bears a stout wire (*s*), called the main electrode, projecting vertically upwards along the axis of a brass tube open at each end, fixed in an aperture in the roof so as to project upwards and downwards, as shown in fig. 9.

§ 27. The top of the main electrode bears a brass sliding-piece (*t*), which, when raised a little, serves for umbrella and wind-guard without disturbing the insulation; and when pressed down closes the aperture and puts the electrode metallic connexion with the roof of the instrument. When the instrusection, and is only known to exist in one fossil specimen. In this instrument the wire bearing the gold leaf was connected with a charged Leyden jar, and the semicylinders with the bodies whose difference of potential was to be tested. But various modifications of the divided-cylinder or divided-ring class with the axis vertical and plane of motion horizontal have done some practical work, and one species, the new quadrant electrometer (§ 6), promises to become permanent.

§ 44. The heterostatic principle in one form or other is essential to distinguish between positive and negative. As remarked above (§ 42), the original type of this use of it is to be found in the old system of testing the quality of the charge taken by the diverging straws or gold leaves of the electroscopes used for the observation of atmospheric electricity, which was done by bringing a piece of rubbed sealing-wax into the neighbourhood, and observing whether this caused increase or diminution of the divergence. A doubt which still exists as to the sign[*] of the atmospheric electricity observed by Professor Piazzi Smyth on the Peak of Teneriffe, is owing to the imperfection of this way of applying the principle. It is, indeed, to be doubted in any one instance whether it is not vitreous electricity that the rubbed sealing-wax acquires; and, again (§ 2), it is not certain that the glass case enclosing the gold leaves, especially if very clean and surrounded by a very dry natural atmosphere, screens them sufficiently from direct influence of the piece of sealing-wax to make sure that the divergence due to vitreous electricity could not be increased by the presence of the resinously electrified sealing-wax if held nearer the gold leaves than the upper projecting stem.

§ 45. The heterostatic principle has a very great advantage as regards sensibility over any simple idiostatic arrangement, inasmuch as, for infinitely small differences of potential to be measured, the force is as the squares of the differences in any idiostatic arrangement, but is simply proportional to the difference in every heterostatic arrangement.

VI. *Determination of the Dynamical Equivalent of Heat from the thermal effects of Electric Currents. By* J. P. Joule, *D.C.L., F.R.S., &c.*

Sir W. Thomson, as long ago as 1851, showed that it was desirable to make experiments such as are the subject of the present paper. They have necessarily been delayed until a sufficiently accurate method of measuring resistance was discovered. Such a method having been described by Sir William, and carried out into practice by Professor C. Maxwell and his able coadjutors, the task assigned to me by the Committee of Electric Standards was comparatively simple.

My experiments were commenced nearly two years ago, and the apparent ease with which they could be executed gave promise of their early completion. It was, however, found essential that careful observations of the earth's horizontal magnetic intensity should be frequently made, and these required the construction of apparatus whereby this element could be determined with accuracy and rapidity.

The apparatus finally adopted for this purpose consists of a suspended horizontal flat coil of wire between two fixed similar coils. A current of electricity can be made to traverse all three, communication with the susponded coil being made by the suspending wires themselves according to S W. Thomson's plan. The strength of a current is found by observing t sum of the forces of attraction and repulsion by which the suspended coil urged. The strength of a current can in this manner be determined in a solute measure; for the area of each of the three equal coils being call a, the weight required to counterpoise the force with which the suspended c is urged w, the force of gravity g, and the length of wire in each of the coil l, the current $c=\frac{1}{2l}\sqrt{\frac{agw}{\pi}}$ (1 + correction), the correction being principall due to the distance between the fixed coils. In my instrument, in whic this distance is 1 inch, the diameter of the coils being 12 inches and thei interior core 4 inches, this correction was proved by experiment to b ·1185.

---

[*] Nichol's Cyclopædia, article "Electricity, Atmospheric," edition 1860.

There was, however, considerable difficulty in obtaining an exact measur of the distance between the fixed coils; and I therefore judged that the measure of the currents used in the experiments would be most accuratel obtained by means of a tangent galvanometer, the above-described current-meter being employed to determine the horizontal intensity.

This determination was effected as follows:—Many careful observations of the horizontal intensity by an improved method on Gauss and Weber's system were made alternately with observations of the deflections of a tangent galvanometer and the weighings of the current-meter when the same currents traversed both instruments in succession. Then calling the horizontal intensity H, the angle of deflection θ, and the weighing w, there was obtained a constant $c=\frac{\mathrm{H}\tan\theta}{\sqrt{w}}=\cdot17676$. Hence with these instruments

$$\mathrm{H}=\frac{\cdot17676\sqrt{w}}{\tan\theta}.$$

The experiments for the determinations of horizontal intensity by the use of this formula could be effected in a few minutes, and did not require an alteration in the disposition of any part of the apparatus. It was satisfactory to find that, although the presence of masses of iron at only a few yards distance made the field in which I worked considerably more intense than that due to the latitude, and although I worked at different times of the day, the highest intensity, out of upwards of seventy observations distributed over a year, was 3·6853, and the lowest 3·6607, indicating a much greater degree of constancy than might have been expected.

The galvanometer above mentioned was that employed in the thermal experiments. It had a single circle of $\frac{1}{10}$-inch copper wire, the diameter of which, being measured in many places by a standard rule, gave a radius of ·62723 of a foot. The needle was half an inch long, and furnished with a glass pointer traversing a divided circle of 6 inches diameter. In the experiments the deflections were not far from 26° 34′, the angle at which the influence of the length of the needle within certain limits is inappreciable. It was easy by a magnifier, arranged so as to avoid parallax, to read to one minute. The torsion of the fibre gave only 3′·5 for an entire twist. The trifling correction thus required is applied to the recorded observations of deflection.

The calorimeter first used was a copper vessel upwards of a gallon in n the first, the observer must estimate the most probable earth-reading the moment when the hair was in its sighted position, with the upper to and the metal case in connexion with the two bodies whose difference potential is to be measured. The estimated earth-reading is to be sub- ted from the reading taken in connexion with the bodies to be tested. is difference measures (§ 21) the required difference of potentials between m in units of the instrument. The value of the unit of the instrument ht to be known in absolute electrostatic measure; and the difference of ding found in any experiment is to be multiplied by this, which is called 1) the absolute coefficient of the instrument, to give the required dif- ence of potentials in absolute measure. It so happens that, in the table electrometers of the kind now described which have been hitherto structed, the absolute coefficient is somewhere about ·01, so that one turn the screw, or 100 divisions of the circle, corresponds to somewhere ut one electrostatic unit, with a gramme for the unit of mass, a centi- tre for the unit of distance, and a *second* for the unit of time; but the ferent instruments differ from one another by as much as ten or twenty cent. in their absolute coefficients. In all of these I have found between ee and four Daniell's cells to correspond to the unit division: that is to r, between three hundred and four hundred cells to a full turn of the ew. With great care, the observer may measure small differences of entials by this instrument to the tenth part of a division (or to about lf a Daniell's cell). With a very moderate amount of practice and care, error of as much as a half division may be avoided in each reading.

§ 32. But there are imperfections in the instrument itself which make it ficult or impossible to secure very minute accuracy, especially in measure- nts through wide ranges.

(1) In the first place, I am not sure that the end of the needle rying the hair is protected sufficiently by the wire fence (§ 27) from ctric disturbance to provide against any error from this source, [illegible] sibly introduces serious irregularities.

(2) In the second place, the capacity of the air [illegible] the small [illegible] strument is not sufficient to secure that the potential [illegible] all not differ sensibly with the different distances [illegible] brought to balance the aluminium lever with [illegible] ion. But on this point it is [illegible] remarkable [illegible] upper surface of the guard-plate [illegible] en the hair is in its sighted position [illegible] tively small difference of the [illegible] rim corresponding to [illegible] uses difference of potential [illegible] racting-plate be sent [illegible] turns of the screw from [illegible] sition, the electricity [illegible] ass, so as to increase the charge [illegible] according as the distance [illegible] rew be turned and the [illegible] the case may be [illegible] its previous value [illegible] ractically avoided [illegible] han a few minutes [illegible] above the centre of [illegible]

(3) A third [illegible]

the indications. In most of the instruments hitherto made I have found that the warmth of the hand produces in a few minutes a very notable augmentation of the earth-reading (as it were an increased charge in the jar); but in the last instrument which I have tested (White No. 18) I find the reverse effect, the earth-reading becoming smaller as the instrument is warmed, or larger when it is cooled. I have ascertained that these changes are not due to changes in the electric capacities of the Leyden jars; and I have found that the change, if any, of specific inductive capacity of glass by change of temperature is excessively small, in comparison to what would be required to account for the temperature errors of these instruments, which probably must be due to thermo-elastic properties of the platinum wire, or of the stretching-springs, or of the aluminium balance-lever, or to a combination of the effects depending on such properties; but I have endeavoured in vain, for several years, and made many experiments, to discover the precise cause. It surely will be found, and means invented for remedying the error, now that I have an instrument in which the error is in the opposite direction to that of most of the other instruments. It is of course much greater in some instruments than in others: in some it is so great that the earth-reading is varied by as much as twenty divisions by the warmth of the hand in the course of five or ten minutes after commencing to use the instrument, if it has been previously for some time in a cold place. Its influence may be eliminated, not quite rigorously, but nearly enough so for most practical purposes, by frequently taking earth-readings (§ 30) and proceeding according to the directions of § 31.

(4) A fourth fault in the portable electrometer is, that the diameter of the guard-plate and upper attracting-disk, which ought to be infinite, are not sufficiently great, in proportion to the greatest distance between them, to render the scale quite uniform in its electric value throughout. A careful observer, however, will remedy the greater part of the error due to this defect, by measuring experimentally the relative (or absolute) values of the scale-division in different parts of the range. There will, however, remain uncorrected some irregularity, due to influence of the distribution of electricity over the uncoated inner surface, in the instruments as hitherto made, in all of which the inner surface of the jar is coated with tinfoil only below the guard-plate, so that the upper surface of the guard-plate may be seen clearly, in order that the observer may always see that all is in order about the aluminium square and aperture round it; and particularly that there are no injurious shreds or minute fibres. But the irregular influence of the electrification of the uncoated glass, if found sensible, will be rendered insensible by continuing the tinfoil coating an inch above the upper surface of the guard-plate.

§ 33. All faults, except the temperature error, depend on the smallness of the instrument; and if the observer chooses to regard as portable an instrument of thirty centimetres (or a foot) diameter, with all other dimensions and all details of construction the same as those of the instrument described above, he may have a portable electrometer practically free from three of the four faults described. But it is scarcely to be expected that a small instrument ($12\frac{1}{2}$ centimetres high, and $8\frac{1}{2}$ centimetres in diameter) which may be carried about in the pocket can be free from such errors. They are, however, so far remedied as to be probably not perceptible in the large stationary instrument which I now proceed to describe.

STANDARD ELECTROMETER.

§ 34. This instrument (figs. 12, 13, & 14, Plate VI.) differs from the portable electrometer only in dimensions, and in certain mechanical details, which are arranged to give greater accuracy by taking advantage of freedom from the exigencies of a small portable instrument. It is at present called the standard electrometer, in anticipation of either remedying or of learning to perfectly allow for the temperature error, and of finding by secular experiments on the elasticity of metals that their properties used in the instrument are satisfactory as regards the permanence from year to year, and from century to century, of the electric value of its reading. It is an instrument capable of being applied with great ease to very accurate measurements of differences of potential, in terms of its own unit. The value of the unit for each such standard instrument ought, of course, to be determined with the greatest possible accuracy in absolute measure; and until confidence can be felt as to its secular constancy, determinations should frequently be made by aid of the absolute electrometer.

§ 35. The Leyden jar of the standard electrometer consists of a large thin white-glass shade coated inside and outside to within 6 centimetres of its lip, and placed over the instrument as an ordinary glass shade, to protect against dust, currents of air, and change of atmosphere. It may be removed at pleasure from the cast-iron sole of the instrument, and then the interior works are seen, consisting of:—

(1) A continuous disk of brass supported on a glass stem, in prolongation of a stout brass rod or tube sliding vertically in Vs, in which it is kept by a spring, and resting with its lower flat end on the upper end of a micrometer-screw shaft, shown in fig. 13, where the screw, graduated circle, and stout brass rod are as seen in the instrument; the perforated brass disk (which is intended to keep the round upper end of the screw-shaft in position) is shown in section in fig. 14.

(2) Resting on three glass columns, a guard-plate with a square aperture in its centre, and carrying on its upperside stretching-springs and thin platinum-wire suspension of an aluminium balance-lever, shaped like those of the gauge (§ 13) and the portable electrometer (§ 23) already described, but somewhat larger. The tops of the three glass columns are rounded; a round hole and a short slot in line with this hole are cut in the guard-plate and receive the rounded ends of two of the columns, which are somewhat longer than the third. The flat smooth lower surface of the guard-plate rests simply on the top of the third glass column. The diameter of the round hole and the breadth of the slot in the guard-plate may be about $\frac{1}{\sqrt{2}}$ of the diameter of curvature of the upper hemispherical rounded ends of the glass column, so that the bearing portions of the rounded ends in the round hole and in the slot respectively may be inclined somewhere about 45° to the plane of the plate. This well-known but too often neglected geometrical arrangement gives perfect steadiness to the supported plate, without putting any transverse strain upon the supporting glass columns, such as was almost inevitable, and caused the breakage of many glass stems, before mental inertia opposing deviations from the ordinary instrument-maker's plan (of screwing the guard-plate to brass mountings cemented to the tops of the glass columns) was overcome. It has also the advantage of allowing the guard-plate to be lifted off and replaced in a moment.

(3) Principal electrode projecting downwards through a hole in the sole

C_3.	C_2.	C_1.	Temperature of unit.	Temperature of coil.	Resistance of coil in terms of unit.
° ′	° ′	° ′	°	°	
tan 79 39·5	tan 52 33·3	tan 52 9·3	59·25	58·6	1·0192
tan 71 39·5	tan 47 17·06	tan 46 55·6	48·6	48·5	1·0198
tan 70 16	tan 46 18·11	tan 45 57·4	54·68	57·4	1·0194
tan 71 54·33	tan 47 7·66	tan 46 45·93	......	......	1·0198
tan 62 6	tan 41 30·43	tan 41 13·46	......	......	1·0187
Average	......	......	......	......	1·01938

The average temperature of the calorimeter in the experiments being 13°·55 Cent., and that at which the unit was adjusted 14°·5, the resistance during the experiments must have been 1·01906, which is equal to 33434330 in British measure.

The correction to be applied to the thermometer immersed in air as deduced from the above Table is given by $\frac{123{\cdot}66-12x}{12{\cdot}74}=\frac{356{\cdot}65+18x}{30{\cdot}99}$, whence $x=-1{\cdot}1835$. It appears also that a difference between the temperatures of the calorimeter and air-registering thermometer so corrected, equal to 10·822, gives the unit effect on the former.

Hence the corrected indication of the air-thermometer in the second series of thermal experiments will be $349{\cdot}63-1{\cdot}1835=348{\cdot}4465$. This being 12·5345 in excess of the temperature of the calorimeter, the corrected thermal effect will be $25{\cdot}65-\frac{12{\cdot}5345}{10{\cdot}822}=24{\cdot}4917$, which, after a small further correction for the immersed stem, becomes 24·512.

The thermal capacity in this second series was made up of 95561 grains

Second Series of Thermal Experiments.

Date.	Deflection.	$\tan^2$. Deflection.	Temperature of air.	Temperature of water.	Rise of temperature.	Horizont[illegible] intensity
1866.	° ′					
Sept. 21 ...	29 51·68	·329623	397·4	363·42	30·38	3·6668
„ 22 ...	28 58·4	·306585	362·51	348·06	26·95	3·6707
„ 25 ...	29 14·63	·313472	345·19	386·94	29·75	3·6724
„ 26 ...	29 51·46	·329525	370·84	350·64	29·92	3·6644
„ 27 ...	28 54·78	·305064	365·91	361·71	25·88	3·6665
Oct. 5 ...	29 5·05	·309393	380·66	387·57	24·99	3·6612
„ 6 ...	28 22·54	·291761	426·55	392·77	27·40	3·6688
„ 8 ...	28 8·74	·286198	338·49	335·54	24·04	3·6595
„ 19 ...	28 42·81	·300074	398·56	332·35	31·08	3·6659
„ 20 ...	27 40·13	·274910	395·18	361·90	26·08	3·6654
„ 22 ...	26 40·5	·252409	371·72	388·63	19·12	3·6702
„ 23 ...	27 28·1	·270252	320·07	318·09	22·55	3·6638
„ 25 ...	27 9·63	·263230	275·65	286·25	20·98	3·6620
„ 26 ...	27 42·56	·275855	249·75	257·54	22·15	3·6623
„ 27 ...	28 7·84	·285838	245·96	247·27	23·57	3·6641
	....	·292946	349·63	335·912	25·65	3·6656

[illegible] instrument never wanted [illegible] less than two or three thousand [illegible] and therefore [illegible] instrument. [illegible] accuracy differences [illegible] [illegible]ails.

[illegible]NG-RANGE [illegible]

In this [illegible] guard-plate with aluminium [illegible] as in the standard [illegible] the lower plate is moved [illegible] of the screw and [illegible] that of the standard electrometer. [illegible] structed the step of the screw [illegible] instruments [illegible] simple mechanism [illegible] is in the use of the present instrument [illegible] great [illegible] by more than [illegible] required to prevent [illegible] same diameter as the [illegible] from [illegible] machine or [illegible] the upper plate. Thus the guard-plate [illegible] for stiffness [illegible] the aluminium balance-lever without the lever [illegible] disadvantageous shape, as would be necessary [illegible] thin rim added to it. No glass case [illegible] The smallness of the needle and the great [illegible] in it are such that I find in practice no disturbance [illegible] degree by ordinary currents of air, although [illegible] disk instruments show the influence of sudden [illegible] pressure, such as that produced by opening or shutting [illegible] under a glass shade when out of use, the lower surface [illegible]-plate and the lower surface of the guard-plate [illegible] square should be carefully dusted by a dry [illegible] none of the vital electric organs of an [illegible] by a cloth, as this is almost sure to leave [illegible]

[illegible]he effective range of this instrument is about [illegible] greater force of torsion is given than in the [illegible] smaller attracted disk may be used [illegible] the electric value of one division. The instrument [illegible] nearly, but not quite, the highest potential [illegible] conductor of a good Winter's electric machine [illegible] brushes a foot long.

[illegible]he classification of electrometers [illegible] systematic relations of their chief organic parts [illegible] other principle of classification is presented by the [illegible] used in them, which may be divided into two classes [illegible]

Another source of error which, though it would be finally eliminated by frequent repetition of the experiments, it seemed to be desirable to avoid, was the hygrometric quality of the cotton-wool which enveloped the calorimeter in the second series of experiments. I therefore sought for a material which did not present that inconvenience. The plan finally adopted was to cover the calorimeter first with tinfoil, to place over that two layers of silk net (tulle), and to finish with a second envelope of tinfoil.

A third source of possible error was the circumstance that the silver-platinum alloy, when made positively electrical in distilled water, is slowly acted upon, an oxide of silver as a bluish-white cloud arising from the metal, while hydrogen escapes from the negative electrode. On this account the coil in the experiments of the last series, as well as the subsequent, was well varnished. But it was found at the conclusion of the experiments that the varnish had in a great measure lost its protecting power. This circumstance gave me considerable anxiety: I was, however, ultimately able, by the following facts arrived at after the thermal experiments were completed, to satisfy myself that no perceptible influence had been produced by it on the results:—

1st. The resistance of the coils, after long-continued use had deteriorated the varnish, was not sensibly less than it was after they had been freshly varnished.

2nd. The coil of the 3rd series was, in the unprotected state, immersed in distilled water, and compared with many hundred yards of thick copper wire, unimmersed, having nearly equal resistance. The result showed that the resistance to the current was sensibly the same whether a single cell or five cells of Daniell in a series were used. Now, had any considerable leakage by electrolytic action taken place, it would have been very much less in proportion in the former than in the latter instance.

3rd. When the coils of the second and third series, in the unprotected state, were placed in distilled water, and made the electrodes of a battery of five cells, the deflection was 40′ of a degree on a galvanometer with a coil of 17 inches diameter composed of 18 turns of wire. This deflection indicates a current of about $\frac{1}{400}$ of the average current in the thermal experiments. In this case the chemical action was distinctly visible, but quite ceased to be so when the electrodes were connected by a wire of unit resistance, so as to reduce the potential to that in the thermal experiments.

4th. The coil of No. 2 series being used as a standard, that of No. 3 series, in the unprotected condition, was immersed, first in water, then in oil. The resistance to the current of five Daniell's cells was found to be sensibly equal in the two cases.

Hence there could be no doubt that the loss of heat during the experiments by electrolytic action could not possibly in any instance have been so great as one-thousandth of the entire effect, and was probably not one quarter of that small quantity; whilst in the larger number of experiments, when the varnish was fresh, it must have been *nil.*

The coil used in the third series of experiments was made by bending four yards of platinum-silver wire double, and then coiling it into a spiral, which was supported and kept in shape by being tied with silk thread to a thin glass tube. The terminals were thick copper wires, and the whole was coated with shellac and mastic varnish. The following results were obtained for its resistance. In the first three trials the current was measured anometer with a circle of nine turns 17 inches diameter, and in the [illegible] with [illegible]

[illegible]	[illegible]						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Date.		Declination.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1867.							
June	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
July	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	22, [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	22, [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	23, [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	24, [illegible] A.M.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	24, 4.5 P.M.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	25, 12.15	32 39·5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	25, 4.55	33 10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	26, 12.58	32 33·95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	27, 11.13 A.M.	33 1·6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
,,	27, 4.14 P.M.	32 58·22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Aug.	2, 12.31	31 52·98	·386923	[illegible]	[illegible]	[illegible]	[illegible]
,,	2, 5.18	31 53·77	·387325	[illegible]	[illegible]	[illegible]	[illegible]
,,	3, 12.56	31 37·18	·379056	[illegible]	[illegible]	[illegible]	[illegible]
,,	6, 11.18 A.M.	26 34·35	·250162	439·906	[illegible]	[illegible]	49·7
,,	6, 3.55 P.M.	28 42·8	·300070	457·145	462·056	25·67	49·6
,,	8, 12.17	29 29·25	·319773	465·586	443·204	29·6	49·7
,,	8, 5.45	29 39·25	·324137	499·874	480·564	29·67	[illegible]
,,	9, 1.27	29 33·2	·321491	478·658	469·296	28·8	26·4
,,	10, 11.9 A.M.	29 12·65	·312625	468·344	455·304	28·21	27·4
,,	10, 3.56 P.M.	28 14·47	·288500	519·082	493·136	27·28	28·4
Average	....	......	·3547795	458·699	[illegible]	21·02666	28·362

The above average resistance, reduced to 18°·63 C., the mean temperat in the third series, is ·98953 of the Association unit, or in British meas 32465480.

In the third series, the experiments for the heat of the current, of radi tion, and for horizontal magnetic intensity were alternated in such a man that each class occupied the same portions of the day that the others did. sought in this way to avoid the effects of any horary change in the humidi &c. of the atmosphere or in the magnetic force. Of the thirty experime comprising each class, six were performed at about each of the several hours 11 A.M., 12¼ P.M., 1¾ P.M., 4 P.M., and 5½ P.M.

The calorimeter, protected as already described, was supported on edges of a light wooden frame. It was carefully guarded against draug by screens coated with tinfoil placed at a foot distance. The stirrer c sisted of a vertical copper rod, to which vanes, on the plan of a scr propeller, were soldered at four equidistant places. The rod exten 2 inches above the calorimeter, and was there affixed to a light wooden sl 2 feet long, attached at the upper end to the last spindle of a train of clo wheels. The weight was 35 lbs., which, falling about 2 feet per hour, p duced a continuous revolution of the stirrer at a rate of about 200 in

Third Series of Radiation Experiments.

Date.	Temperature of air.	Temperature of water.	Rise of temperature.	Fall of weig
1867.				in.
June 28, 10.38 A.M.	460·527	481·990	−1·48	31
„ 28, 3.53 P.M.	513·687	506·770	0·75	28·2
„ 29, 11.55 A.M.	493·088	473·930	1·82	28
„ 29, 4.40 P.M.	526·185	508·480	1·88	28·5
July 1, 1.23	469·368	442·114	2·46	27·5
„ 2, 10.58 A.M.	404·842	439·790	−2·82	27
„ 2, 4.5 P.M.	401·779	450·930	−4·1	28·5
„ 4, 11.46 A.M.	492·210	427·517	5·97	28
„ 4, 4.42 P.M.	541·007	484·927	5·1	26·5
„ 20, 1.0	416·237	409·044	1·03	28·75
„ 22, 11.5 A.M.	474·393	439·140	3·32	30
„ 22, 3.50 P.M.	486·267	480·106	0·8	28·75
„ 23, 11.41 A.M.	451·029	456·947	−0·1	28·4
„ 23, 4.49 P.M.	475·319	486·113	−0·65	28·5
„ 24, 12.54	441·677	460·780	−1·48	26·5
„ 25, 10.40 A.M.	435·863	410·237	2·43	28
„ 25, 3.27 P.M.	515·653	460·939	5·03	28·8
„ 26, 11.29 A.M.	441·256	447·526	−0·2	28·5
„ 26, 4.49 P.M.	435·776	472·503	−3·0	29
„ 27, 1.7	404·58	433·444	−2·28	29·8
Aug. 2, 10.55 A.M.	369·966	374·18	−0·15	29·75
„ 2, 3.50 P.M.	407·34	406·42	0·17	27·8
„ 3, 11.30 A.M.	435·813	401·187	3·24	28·6
„ 3, 4.33 P.M.	476·691	446·393	2·9	27
„ 6, 1.15	457·87	447·843	1·05	28·9
„ 8, 10.46 A.M.	442·403	426·304	1·68	29
„ 8, 4.17 P.M.	489·901	463·143	2·42	29·7
„ 9, 11.51 A.M.	466·428	453·149	1·27	26·5
„ 9, 5.37 P.M.	490·308	484·753	0·66	27·9
„ 10, 1.20	502·96	472·469	2·82	28·6
	460·6808	451·6356	1·018	28·498

[illegible] of the stirrer left nothing to be desired. [illegible] before an experiment commenced, and kept [illegible] the thermometer had been made.

[illegible] as in the second series, lasted [illegible] observations of the thermometer [illegible] of the temperature of the air, and forty [illegible]

[illegible] to be applied to the air-registering thermometer [illegible]

[illegible] experiments of this third series, is found from [illegible]

[illegible], whence x, the quantity to be added to the [illegible]

[illegible] the thermal experiments, =2·[illegible]. The [illegible] virtually 0·073 higher than that of the [illegible]

[illegible] of Horizontal Magnetic Intensity.

Date.	Galvanometer deflection, θ.	Weighing by current-meter. w.	H.–[illegible]
[illegible]	° ′	grs.	
[illegible]	[illegible] 21·42	253·64	[illegible]
[illegible]	25 43·[illegible]	[illegible]	[illegible]
[illegible]	25 12·56	96·64	[illegible]
[illegible]	38 23·56	[illegible]	[illegible]
[illegible]	38 59·25	[illegible]	[illegible]
[illegible]	38 49·94	[illegible]	[illegible]
[illegible]	26 24·55	[illegible]	[illegible]
[illegible]	26 10·55	[illegible]	[illegible]
[illegible]	39 18·9	[illegible]	[illegible]
[illegible]	41 11·35	[illegible]	[illegible]
[illegible]	41 21·4	[illegible]	[illegible]
[illegible]	32 5·1	[illegible]	[illegible]
[illegible]	31 56·15	[illegible]	[illegible]
[illegible]	39 52·95	[illegible]	[illegible]
[illegible]	40 24·9	[illegible]	[illegible]
[illegible]	41 27·95	[illegible]	[illegible]
[illegible]	34 [illegible]	[illegible]	[illegible]
[illegible]	33 [illegible]	[illegible]	[illegible]
[illegible]	43 [illegible]	[illegible]	
[illegible]	42 [illegible]	[illegible]	
[illegible]	41 [illegible]	[illegible]	
[illegible]	34 [illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		
[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	
[illegible] A.M.	[illegible]		
[illegible] P.M.	[illegible]		
[illegible]	[illegible]		
[illegible]	[illegible]		

[illegible] the un[illegible]
[illegible]rature [illegible]
[illegible]

part of the thermometer-stem, the corrected thermal effect in the third
is found to be 30·5821.

The average capacity of the calorimeter was equal to that of 93859
of water, being made up of 91531 grs. distilled water, 22364 grs. of
486 grs. of tin (the weight of the coating next the calorimeter), 52 grs.
net (half that employed), the thermometer, coil, and corks.

The equivalent deduced from the third series is therefore

$$\frac{\left\{\frac{\cdot 62723}{6\cdot 2832}\times 3\cdot 6777\right\}^2\times \cdot 35478\times 32465480\times 3600}{\frac{30\cdot 5821}{12\cdot 951}\times 93859}=25217.$$

The equivalents above arrived at are:—

From Series 1. Average of 10, 25335.
From Series 2. Average of 15, 25366.
From Series 3. Average of 30, 25217.

The extra precautions taken in the last series entitle the last figure to be taken as the result of the inquiry. Reduced to weighings *in vacuo* it becomes 25187.

SIXTH REPORT—EXETER, AUGUST 1869.

The Committee consists of Professor Williamson, Professor Sir C. Wheatstone, Professor Sir W. Thomson, Professor W. A. Miller, Dr. A. Matthiessen, Mr. Fleeming Jenkin, Sir Charles Bright, Professor Maxwell, Mr. C. W. Siemens, Mr. Balfour Stewart, Mr. C. F. Varley, Professor G. C. Foster, Mr. Latimer Clark, Mr. D. Forbes, Mr. Charles Hockin, and Dr. Joule.

The Electrical Standard Committee have this year had comparatively few meetings, and the results of the experiments made by the individual Members do not call for a Report of any length. It is, however, thought desirable to print at once, as Appendices, the important results obtained by Professor Clerk Maxwell, in determining the ratio of the electromagnetic and electrostatic series of units, and also a description of Sir Wm. Thomson's experiments on the same subject.

Description of Sir Wm. Thomson's Experiments made for the Determination of v, *the Number of Electrostatic Units in the Electromagnetic Unit.* By W. F. King.

The two principal pieces of apparatus used in these experiments were the absolute electrometer and the electrodynamometer. The former of these instruments was described at the last Meeting of the Association, and a description of it is printed in the Report. Plate VII. illustrates the arrangements described in what follows.

The electrodynamometer consists of two large coils of fine copper wire, and a smaller coil of still finer wire. The two large coils are about 30 centims. diameter, and are placed vertical, in planes parallel to one another the distance between the large coils is 15 centims. (equal to their radius) The smaller coil is suspended between the large coils by a copper wire o
thickness as to give the coil a time of vibration such that it com

tes a period in about thirteen seconds. The upper end of the suspending re is attached to a milled head, and this head can be turned round by the gers. The lower end of the wire is firmly fixed to the coil, and is in tallic connexion with one end of it. To the other end of the coil is dered a spiral of very fine platinum wire, which hangs directly below the il, and its lower end is cemented to the dry woodwork of the instrument. the fixed end of the spiral coil a copper wire is attached, whose other end soldered to a binding-screw in an accessible position.

On one side of the small or movable coil is fixed a plane mirror, and in ont of the mirror, at a distance of about 450 centims., the scale is fixed on hich the observations are read. A paraffin-lamp wire, to give dark line in age of flame, and lens are used in the ordinary way for finding accurately e angle through which the coil turns. It is never greater than ·05. Its ue amount can be determined to within $\frac{1}{10}$ per cent.

The connexions are not very intricate, and are traced thus:—Starting rom one pole of the battery (the battery used was sixty sawdust Daniell's n series), the current goes in at one end of large coil No. 1, and from the ther end of No. 1 the current goes to either end of the movable coil; and he end of the movable coil at which we suppose the current to be coming ut is connected with the end of No. 2 large coil, similar to the end of No. 1, o which the battery was first attached, that is to say, the end which will make the current go round in the same direction in both the large coils. When the current leaves the extreme end of No. 2, it passes through a 10,000 B.A. resistance-box; the current is completed by connecting the other end of the resistance-box with the pole of the battery not already engaged.

The absolute electrometer is used in the ordinary way for measuring differences of potential, and its electrodes are connected, one to the end of the dynamometer coil No. 1, which is joined to the battery, and the other electrode is fixed to the end of the resistance-box, which is connected to the other pole of the battery. Thus the greatest difference of potential in the arrangement is measured by the absolute electrometer. An electrometer-key is used to reverse these connexions in the course of the experiments.

There is only one other part of the arrangement to be explained, and that is the method of observing the resistance of the dynamometer coils while the experiments are going on. This was done by means of the resistance-box in the circuit and an electrometer. At one time the standard electrometer was used for this purpose, but more lately the quadrant, rendered unsensitive, was employed. Both these instruments are described in the last Report.

To take the resistance of the coils, the electrodes of the electrometer were first placed on the extreme ends of the three coils, and the difference of potential was ascertained. The electrodes were then shifted to the ends of the resistance-box, and the difference of potentials of its two ends was found. This gives at once the resistance of the coils.

There are two things which have to be done before the experiments are commenced. One is the determination of the moment of inertia of the movable coil. This is done at the beginning and end of a long series of experiments, by comparing it with a ring whose moment of inertia is known. The other is done every day, and it is finding the time of vibration of the small coil after all the connexions have been made and the coil put into its place. This was done both with the current from the battery flowing through the coils and with no current flowing; but this variation was of very little consequence, as no difference could be detected in the time. When the dynamometer is set up, care is taken to neutralize the effects of the earth's magnetism by a large number of magnets fixed at a great distance from the coils. If the adjustment of the magnets is perfect, there is no alteration of the position of the spot of light when the current is reversed through the coils by the battery-key. Up to the present time (May 1868) various causes have prevented the obtainment of as satisfactory results as the method described above allows us to expect. Eleven sets of experiments, made at various dates, from March 10 to May 8 of the present year, have indicated values for v, of which the greatest was 292×10^8, the smallest $275{\cdot}4 \times 10^8$, and the mean $282{\cdot}5 \times 10^8$ centimetres per second. Sir W. Thomson intends to continue the investigation, hoping to attain much greater accuracy.

[P.S. Nov. 1869. A new form of absolute electrometer has now been completed and brought into use, with good promise as to accuracy and convenience. A glass jar constituting the "Leyden battery" contains within it the "absolute electrometer" proper, the "idiostatic gauge," and the "replenisher." One observer can use it effectively; although it is more easily worked by two, one maintaining constant potential in the Leyden jar by aid of the idiostatic gauge and the replenisher, and the other attending to the absolute electrometer (main balance and micrometer-screw). The main balance, giving electric weighing in known weights, is as steady and as easily used as any of the "attracted disk" electrometers, whether portable or stationary, described in previous Reports.]

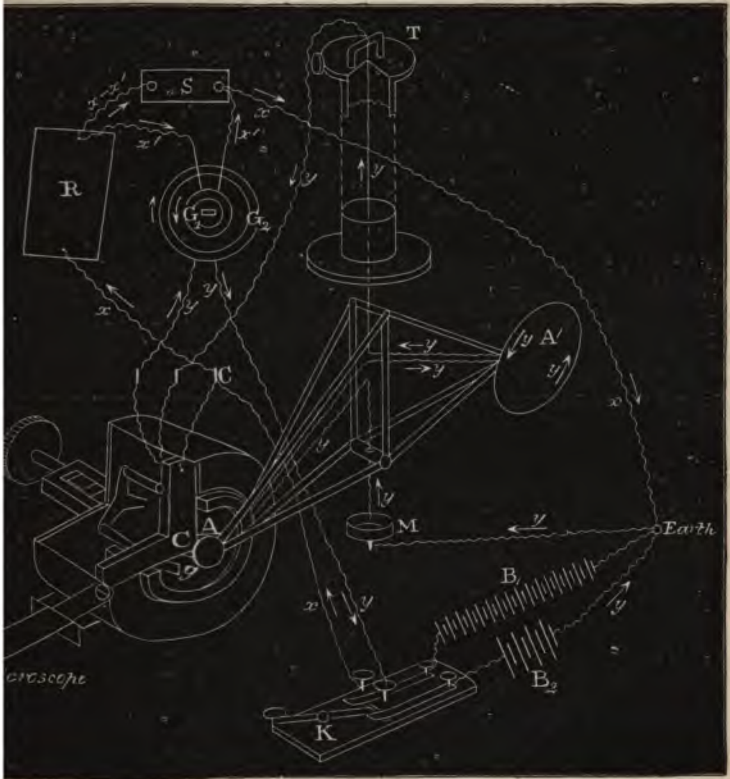
Experiments on the Value of v, *the Ratio of the Electromagnetic to the Electrostatic Unit of Electricity.* By J. CLERK MAXWELL.

The experiments consisted in observing the equilibrium between the electrostatic attraction of two disks, at a certain difference of potential, and the electromagnetic repulsion of two coils traversed by a certain current. For this purpose one of the disks, with one of the coils at its back, was attached to one arm of a torsion-balance, while the other, with the other coil at its back, was capable of being moved to various distances from the suspended disk by a micrometer-screw. Another coil, traversed by the same current in the opposite direction, was attached to the other arm of the torsion-balance, so as to do away with the effect of terrestrial magnetism.

The fixed disk was larger than the suspended disk, and the latter, when in its zero position, had its surface in the same plane as that of a "guard-ring," as in Sir W. Thomson's electrometers. Its position and motion were observed by means of a microscope, directed to a graduated glass scale, connected with the disk. When the microscope was adjusted so that the image of the zero line on the glass scale coincided with the cross wires of the microscope, the very smallest motion of the scale could be easily detected, so that the observations were very rapid. The disk was brought to zero by the tangent-screw at the top of the suspension-wire, and its equilibrium was always observed at zero. The equilibrium, when the electrical forces were applied, was always unstable. This electrical balance was made by Mr. Becker. The experiments were made in the laboratory of Mr. Gassiot, who kindly gave the use of his great battery for the purpose. Mr. Willoughby Smith lent his resistance-coils, of 1,102,000 ohms; Messrs. Forde and Fleeming Jenkin lent a galvanometer, a resistance-box, a bridge and a key; and Mr. C. Hockin undertook the observation of the galvanometer, and the testing of the galvanometer, the resistances, and the micrometer-screw.

difference of potentials of the disks was compared with the current in ls as follows:—One electrode of the great battery was connected with the lisk, and the other with the case of the instrument and the guard-ring e suspended disk. They were also connected through the great re- e R, and the primary coil of the galvanometer G_1, shunted with a re- e S.

nall Grove's battery was employed to send a current through the three id the secondary coil of the galvanometer G_2.



ended disk and coil.
iterpoise disk and coil.
d disk and coil.
t battery. B_2. Small battery.
aary coil of galvanometer.
ndary coil.
t resistance. S. Shunt.
ble key. *g*. Graduated glass scale.

C. Electrode of fixed disk.
x. Current through R.
x'. Current through G_1. $x-x'$. Current through S.
y. Current through the three coils and G_2.
M. Mercury cup. T. Torsion head and tangent screw.

quarter of the micrometer-box, disks, and coils is cut away to show the interior. e of the instrument is not shown. The galvanometer and shunts were 10 feet from tric balance.

ilibrium of the electric balance was obtained by working the micro- , and so adjusting the distance of the disks. At the same time equiliin France (*vide* Daguin, Jamin, Becquerel, De la Rive, and others). The ne step would naturally be, when comparing different circuits, to reduce all r sistances into a length of some one standard wire, though this wire mig not form part of all or of any of the circuits, and then to treat the unit leng of that standard wire as a unit of resistance. Accordingly we find Lenz (1838[*]) stating that 1 foot of No. 11 copper wire is his unit of resistance, a that it is 19·9 times as great as the unit he used in 1833[†], which was a c tain constant part of the old circuit. In the earlier paper the resistances treated as lengths, in the later as so many "units."

Lenz appears to have chosen his unit at random, and apparently with the wish to impose that unit upon others. A further advance is seen wh Professor Wheatstone, in his well-known paper of 1843[‡], proposes 1 foot copper wire, weighing 100 grains, not only as a unit, but as a standard of sistance, chosen with reference to the standard weight and length used in t country. To Professor Wheatstone also appears due the credit of constru ing (in 1840) the first instruments by which definite multiples of the res ance-unit chosen might be added or subtracted at will from the circuit[‡]. was closely followed by Poggendorff[§] and Jacobi[‖], the description of wh apparatus, indeed, precedes that of the Rheostat and Resistance-coils, altho the writer understands that they acknowledge having cognizance of those ventions. Resistance-coils, as the means of adding, not given lengths, given graduated resistances to any circuit, are now as necessary to the e trician as the balance to the chemist.

In 1846 Hankel[¶] used as unit of resistance a certain iron wire; in 1 I. B. Cooke[**] speaks of a length of wire of such section and conduct power as is best fitted for a standard of resistance. Buff[††] and Horsfor in the same year reduce the resistance of their experiments to lengths given German-silver wire, and as a further definition they give its valu compared with pure silver. To avoid the growing inconvenience of multiplicity of standards, Jacobi[§§] (in 1848) sent to Poggendorff and ot a certain copper wire, since well known as Jacobi's standard, desiring they would take copies of it, so that all their results might be expresse one measure. He pointed out, with great justice, that mere definition o standard used, as a given length and weight of wire, was insufficient, that good copies of a standard, even if chosen at random, would be prefe to the reproduction in one laboratory of a standard prepared and ke another. The present Committee fully indorse this view, although the nition of standards based on weights and dimensions of given materials since then gained greatly in precision.

Until about the year 1850 measurements of resistance were confined, few exceptions, to the laboratory; but about that time underground graphic wires were introduced, and were shortly followed by submarine ca in the examination and manufacture of which the practical engineer found the benefit of a knowledge of electrical laws. Thus in 1847 the of of the Electric and International Telegraph Company used resistance- made by Mr. W. F. Cooke, apparently multiples of Wheatstone's ori standard, which was nearly equal to the No. 16 wire of commerce; and

---

[*] Pogg. Ann. vol. xlv. p. 105.
[†] Pogg. Ann. vol. xxxiv. p. 418.
[‡] Phil. Trans. 1843, vol. cxxxiii. p. 303.
[§] Pogg. Ann. vol. lii. p. 511.
[‖] Pogg. Ann. vol. lii. p. 526, vol. liv. p. 347.
[¶] Pogg. Ann. vol. lxix. p. 255.
[**] Phil. Mag. New Series, vol. xxx. p. 385.
[††] Pogg. Ann. vol. lxxiii. p. 497.
[‡‡] Pogg. Ann. vol. lxx. p. 238, and Silliman's Journ. vol. v. p. 36.
[§§] Comptes Rendus, 1851, vol. xxxiii. p. 277.

. Varley[*] states that, even at that date, he used a rough mode of
tance testing." In 1850, Lieut. Werner Siemens[†] published two methods
etermining, by experiments made at distant stations, the position of "a
;"—that is to say, a connexion between the earth and the conducting-
of the line at some point between the stations. In one of these plans a
tance equal to that of the battery is used, and the addition of resistances
so suggested; and Sir Charles Bright, in a Patent dated 1852[‡], gives an
unt of a plan for determining the position of a fault by the direct use of
tance-coils. Since that time new methods of testing for faults and of
ining the quality of materials employed, and the condition of the line,
been continually invented, almost all turning, more or less, on the mea-
ment of resistance; greater accuracy has been continually demanded in
djustment of coils and other testing-apparatus, until we have now reached
int where we look back with surprise at the rough and ready means by
h the great discoveries were made on which all our work is founded.

he first effect of the commercial use of resistance was to turn the "feet"
e laboratory into "miles" of telegraph wire. Thus we find employed
its, in England the mile of No. 16 copper wire[§], in Germany the German
of No. 8 iron wire, and in France the kilometre of iron wire of 4 milli-
es diameter. Several other units were from time to time proposed by
sdorf[||], Jacobi[¶], Marie-Davy[**], Weber[††], W. Thomson[‡‡], and others,
a gradually increasing perception of the points of chief importance in a
lard; but none of these were generally accepted as the one recognized
ure in any country. To remedy the continually increasing evils arising
the discrepancies invariably found between different sets of coils, Dr.
ie Siemens (in 1860[§§]) constructed standards, taking as unit the re-
ice of a column of chemically pure mercury 1 metre long, having a sec-
equal to 1 millimetre square, and maintained at the temperature of 0°
grade[|| ||]. Dr. Siemens supposed that this standard could be reproduced
ut much difficulty where copies could not be directly obtained. Mer-
had been proposed before as a fitting material for a standard by Marie-
and De la Rive; but Dr. Siemens merits especial recognition, as the
and apparatus he issued have been made with great care, and have ma-
ly helped in introducing strict accuracy[¶¶].

e question had reached this point when (in 1861) the British Associa-
at the suggestion of Professor W. Thomson, appointed a Committee to
mine the best standard of electrical resistance. This Committee, aided
grant from the Royal Society, has now issued a new standard, the sub-
f the present paper.

---

etter to writer, 1865.

[†] Pogg. Ann. vol. lxxix. p. 481.

atent No. 14,331, dated Oct. 21, 1852.

. size much used in underground conductors, and equal in resistance to about double
igth of the common No. 8 iron wire employed in aërial lines.

iebig's Ann. vol. lxxxv. p. 155.

[¶] Pogg. Ann. vol. lxxviii. p. 173.

nn. Chim. et Phys. 3rd series, vol. ix. p. 410.

[††] Pogg. Ann. vol. lxxxii. p. 337.

hil. Mag., Dec. 1851, 4th ser. vol. ii. p. 551.

[§§] Pogg. Ann. vol. cx. p. 1.

r. Siemens, while retaining his definition, has altered the value of his standard
2 per cent. since the first issue; and it is doubtful whether even the present standard
ents the definition truly: his experiments were made by weight; and in reducing
ults to simple measurements of length he has used a specific gravity for mercury of
instead of 13·596 as given by Regnault, 13·595 by H. Kopp, and 13·594 by Balfour
t. (1873. The error due to this cause has since been corrected.)

Many of the different units described above were represented by resistance-coils in
ternational Exhibition of 1862: *vide* Jury Report, Class XIII. p. 83, where their
e values are given: *vide* also Appendix A to present paper.

The writer has hitherto described those units only which are founded more or less arbitrary size and weight of some more or less suitable mate but measurements of resistance can be conceived and carried out enti without reference to the special qualities of any material whatever. In Kirchhoff* had already effected a measurement of this kind; but it is to Weber† that we owe the first distinct proposal (in 1851) of a definite sy of electrical measurements, according to which resistance would be meas in terms of an absolute velocity. This system of measures he called abs electromagnetic measure, in analogy with Gauss's nomenclature of abs magnetic measure. The Committee have decided that Weber's propos far preferable to the use of any unit of the kind previously described. ting aside the difficulties in the way of their reproduction, which are b means contemptible, arbitrary material standards, whether of mercury, silver, platinum, or any other material, would be heterogeneous isolated without any natural connexion with any other physical units. The unit posed by Weber, on the other hand, forms part of a symmetrical na system, including both the fundamental units of length, time, and mass, the derived electrical units of current quantity and electromotive force. M over it has been shown by Professor W. Thomson‡, who accepted and tended Weber's proposal immediately on its appearance, that the unit o solute work, the connecting link between all physical forces, forms part c same system, and may be used as the basis of the definition of the abs electromagnetic units.

The full grounds of the choice of the Committee could only be expl by a needless repetition of the arguments given in the reports already to the British Association. It will be sufficient here to state that, in th solute electromagnetic system, the following equations exist between th chanical and electrical units:—

$$W=C^{2}Rt, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; .$$

where W is the work done in the time t by the current C con through a conductor of the resistance R. This equation expresses and Thomson's law.

$$C=\frac{E}{R}, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; .$$

where E is the electromotive force. This equation expresses Ohm'

$$Q=Ct, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; .$$

expressing a relation first proved by Faraday, where Q is the quan electricity conveyed or neutralized by the current in the time t. Fina whole system is rendered determinate by the condition that the unit of the unit current must produce the unit force on the unit pole (Ga the unit distance. If it is preferred to omit the conception of magn this last statement is exactly equivalent to saying that the unit curre ducted round two circles of unit area in vertical planes at right angles other, one circuit being at a great distance D above the other, will c couple to act between the circuits of a magnitude equal to the recipr he cube of the distance D. This last relation expresses the proposa by Weber for connecting the electric and magnetic measure. These f

---

[*] ...m. vol. lxxvi. p. 412. † Ibid. vol. lxxxii. p. 337.

[‡] ..., Dec. 1851, 4th series, vol. ii. p. 551.

ns serve to define the four magnitudes R, C, Q, and E, without reference ny but the fundamental units of time, space, and mass; and when reduced hese fundamental units, it will be found that the measurement of R in-ves simply a velocity, *i. e.* the quotient of a length by a time. It is for reason that the absolute measure of resistance is styled $\frac{\text{metre}}{\text{second}}$ or $\frac{\text{foot}}{\text{second}}$, isely as the common non-absolute unit of work involving the product of eight into a length is styled kilogrammetre or foot-pound. The Com-tee have chosen as fundamental units the second of time, the metre, and mass of the Paris gramme. The metrical rather than the British system nits was selected, in the hope that the new unit might so find better ac-ance abroad, and with the feeling that while there is a possibility that may accept foreign measures, there is no chance that the Continent will pt ours. The unit of force is taken as the force capable of producing in second a velocity of one metre per second in the mass of a Paris gramme, the unit of work as that which would be done by the above force acting ugh one metre of space. These points are very fully explained in the ish Association Report for 1863, and in the Appendix C to that Report Professor J. Clerk Maxwell and the writer.

he magnitude of the $\frac{\text{metre}}{\text{second}}$ is far too small to be practically convenient, the Committee have therefore, while adopting the system, chosen as r standard a decimal multiple 10^{10} times as great as Weber's unit e $\frac{\text{millimetre}}{\text{second}}\Big)$, or 10^7 times as great as the $\frac{\text{metre}}{\text{second}}$. This magnitude ot very different from Siemens's mercury unit, which has been found venient in practice. It is about the twenty-fifth part of the mile of No. mpure copper wire used as a standard by the Electric and International pany, and about once and a half Jacobi's unit*.

t was found necessary to undertake entirely fresh experiments in order letermine the actual value of the abstract standard, and to express the e in a material standard which might form the basis of sets of resistance-s to be used in the usual manner. These experiments, made during two rs with two distinct sets of apparatus by Professor J. C. Maxwell and the ter, according to a plan devised by Professor W. Thomson, are fully de-bed in the Reports to the British Association for 1863 and 1864.

he results of the two series of experiments made in the two years agree hin 0·2 per cent., and they show that the new standard does not probably r from true absolute measure by 0·1 per cent.† It is not far from the n of a somewhat widely differing series of determinations by Weber.

n order to avoid the inconvenience of a fluctuating standard, it is proposed the new standard shall not be called "absolute measure," or described as any $\frac{\text{metre}}{\text{seconds}}$, but that it shall receive a distinctive name, such as the B. A. , or, as Mr. Latimer Clark suggests, the "Ohmad"‡; so that, if hereafter roved methods of determination in absolute measure are discovered or er experiments made, the standard need not be changed, but a small co-ient of correction applied in those cases in which it is necessary to con-

---

This last number may be 30 per cent. wrong, as the writer has never been in posses- of an authenticated Jacobi standard, and has only arrived at a rough idea of its value series of published values which afford an indirect comparison.

ide Appendix B.

ote, 1873. The name Ohm has been adopted.

vert the B. A. measure into absolute measure. Every unit in popular u has a distinctive name; we say feet or grains, not units of length or units weight; and it is in this way only that ambiguity can be avoided. Th are many absolute measures, according as the foot and grain, the millime and milligramme, the metre and gramme, &c. are used as the basis of system. Another chance of error arises from the possibility of a mistake i the decimal multiple used as standard. For all these reasons, as well as t convenience of expression, the writer would be glad if Mr. Clark's propos were adopted and the unit called an Ohmad.

Experiments have been made for the Committee by Dr. Matthiessen, t determine how far the permanency of material standards may be relied o and under what conditions wires unaltered in dimension, in chemical compo sition, or in temperature change their resistance. Dr. Matthiessen has esta blished that in some metals a partial annealing, diminishing their resistance does take place, apparently due to age only. Other metals exhibit no alte ation of this kind; and no permanent change due to the passage of volta currents has been detected in any wires of any metal—a conclusion contrar to a belief which has very generally prevailed.

The standard obtained has been expressed in platinum, in a gold-silv alloy, in a platinum-silver alloy, in a platinum-iridium alloy, and in mercur Two equal standards have been prepared in each metal; so that should tin or accident cause a change in one or more, this change will be detected l reference to the others. The experiments and considerations which have l to the choice of the above materials are fully given in the Report to t British Association for 1864. The standards of solid metals are wires of fr 0·5 millim. to 0·8 millim. diameter, and varying from one to two metres length, insulated with white silk wound round a long hollow bobbin, and th saturated with solid paraffin. The long hollow form chosen allows the co rapidly to assume the temperature of any surrounding medium, and they c be plunged, without injury, into a bath of water at the temperature at wh they correctly express the standard. The mercury standards consist of t glass tubes about three quarters of a metre in length. All these standa are equal to one another at some temperature stated on each coil, and ly between 14°·5 and 16°·5 C. None of them, when correct, differ more tl 0·03 per cent. from their value at 15°·5 C.

Serious errors have occasionally been introduced into observations by sistance at connexions between different parts of a voltaic circuit, as per metallic contact at these points is often prevented by oxide or dirt of s kind. Professor Thomson's method of inserting resistances in the Wh stone balance (differential measurer) has been adopted for the standards; in the use of the copies which have been issued it has been thought t sufficient accuracy would be attained by the use of amalgamated merc connexions.

In the standards themselves permanence is the one paramount qualit be aimed at; but in copies for practical use a material which changes li in resistance with change of temperature is very desirable, as otherwise m time is lost in waiting till coils have cooled after the passage of a curr moreover large corrections have otherwise to be employed when the coils used at various temperatures; and these temperatures are frequently known with perfect accuracy. German silver, a suitable material in respect, and much used hitherto, has been found to alter in resistance, in s cases, without any known cause but the lapse of time, since the change been observed where the wires were carefully protected against mechan chemical injury. A platinum-silver alloy has been preferred by the Com-ttee to German silver for the copies which have been made of the standard. ese have been adjusted by Dr. Matthiessen so as to be correct at some mperature not differing more than 1° from 15°·5 C. The resistance of tinum silver changes about 0·031 per cent. for each degree Centigrade thin the limits of 5° above and below this temperature; this change is even s than that of German silver. The new material seems also likely to be ry permanent, as it is little affected by annealing. The form of the copies the same as that of the standard, with the exception of the terminals, which e simple copper rods ending in an amalgamated surface. Twenty copies ve been distributed gratis, and notices issued that others can be procured m the Committee for £2 10*s*. The Committee also propose to verify, at a all charge, any coils made by opticians, as is done for thermometers and rometers at Kew.

Dr. Matthiessen reports, with reference to the question of reproduction, at given weights and dimensions of several pure metals might be employed r this purpose *if absolute care were taken.* The reproduction, in this man-er, of the mercury unit, as defined by Dr. Siemens, differs from the standards sued by him in 1864 about 8·2 per thousand if the same specific gravity mercury be used for both observations*. Each observer uses for his final lue the mean of several extremely accordant results. It is therefore to be ped that the standard will never have to be reproduced by this or any similar ethod. On the other hand, four distinct observers, with four different ap-ratus, using four different pairs of standards issued respectively by Dr. iemens and the Committee, give the B. A. unit as respectively equal to ·0456, 1·0455, 1·0456, and 1·0457 of Siemens's 1864 unit†. It is certain at two resistances can be compared with an accuracy of one part in one undred thousand—an accuracy wholly unattainable in any reproduction by eights and measures of a given body, or by fresh reference to experiments n the absolute resistance. The above four comparisons, two of which were ade by practical engineers, show how far the present practice and require-ents differ from those of twenty and even ten years ago, when, although he change of resistance due to change of temperature was known, it was not hought necessary to specify the temperature at which the copper or silver tandard used was correct. The difficulty of reproducing a standard by simple ference to a pure metal, further shows the unsatisfactory nature of that ystem in which the conducting power of substances is measured by compa-ison with that of some other body, such as silver or mercury. Dr. Matthi-ssen has frequently pointed out the discrepancies thus produced, although e has himself followed the same system pending the final selection of a unit f resistance. It is hoped that for the future this quality of materials will lways be expressed as a specific resistance or specific conducting power re-rred to the unit of mass or the unit of volume, and measured in terms of he standard unit resistance, that the words conducting power will invariably e used to signify the reciprocal of resistance, and that the vague terms good nd bad conductor or insulator will be replaced, in all writings aiming at ientific accuracy, by those exact measurements which can now be made with r greater ease than equally accurate measurements of length.

There is every reason to believe that the new standard will be gladly ac-pted throughout Great Britain and the colonies. Indeed the only obstacle

---

* If Dr. Matthiessen uses the sp. gr. of 13·596, as given by Regnault, the difference from r. Siemens's standard is 5 per thousand.

† 1873. The value now adopted is 1·0486.

to its introduction arises from the difficulty of explaining to inq
the unit is. The writer has been so much perplexed by
question, finding himself unable to answer it without entering
the subject of electrical measurement, that he has been led to
following definitions, in which none but already established
referred to.

The resistance of the absolute $\frac{\text{metre}}{\text{second}}$ is such that the curre
in a circuit of that resistance by the electromotive force due to a
1 metre long moving across a magnetic field of unit intensity*,
larly to the lines of force and to its own direction, with a velocit
per second, would, if doing no other work or equivalent of wor
that circuit in one second of time a total amount of heat equiv
absolute unit of work—or sufficient heat, according to Dr. Jo
ments, to heat 0·0002405 gramme of water at its maximum
Centigrade.

The new standard issued is as close an approximation as could
by the Committee to a resistance ten million times as great as
$\frac{\text{metre}}{\text{second}}$. The straight bar moving as described above in a mag
unit intensity would require to move with a velocity of ten
metres per second to produce an electromotive force which would
circuit of the resistance of the new standard the same current
produced in the circuit of one $\frac{\text{metre}}{\text{second}}$ resistance by the electro
due to the motion of the bar at a velocity of one metre per second
locity required to produce this particular current† being in each
portional to the resistance of the circuit, may be used to measure
ance; and the resistance of the B. A. unit may therefore be said
millions of metres per second, or $10^7 \frac{\text{metres}}{\text{second}}$.

It is feared that these statements are still too complex to fulfil
of popular definitions; but they may serve at least to show how a
may be used to measure a resistance by using the velocity with w
certain circumstances, part of a circuit must be made to move in
duce a given current in a circuit of the resistance to be measu
current in the absolute system is the unit current, and the work do
unit current in the unit of time is equal to the resistance of the
results from the first equation stated above.

Those who from this slight sketch may desire to know mo
subject will find full information in the Reports of the Committ
British Association in 1862, 1863, and 1864. The Committee co
act with the view of establishing and issuing the correlative uni
rent, electromotive force, quantity, and capacity, the standard
for which will, it is proposed, be deposited at Kew along wit
standards of resistance already constructed with the funds vot
Royal Society.

---

* Gauss's definition.

† This current is the unit current, and, if doing no other work or equival
would develop, in a circuit of the resistance of the B. A. unit, heat equiv
units of work, or enough to raise the temperature of 2405 gramme
m density 1° Centigrade.

cal Resistance.

Bréquet.	Swiss.
0·03123	0·02924
0·03279	0·03071
0·06520	0·06106
0·09416	0·08817
0·09775	0·09149
0·1024	**0·0959**
0·9491	0·8889
1·000	0·9365
1·068	1·000
1·391	1·303
2·622	2·456
5·882	5·509

ıens's 1864 issue has been c

o
n
st
of
e
d
y
d

CANTOR LECTURES.

On Submarine Telegraphy. By Fleeming Jenkin, *Esq., C.E., F.R.S.*

[Delivered before the Royal Society of Arts.]

LECTURE I.

(Monday, January 29, 1866.)

The Insulated Conductor and its Properties.

The lecturer stated that in the lectures he was about to deliver he should aim rather at spreading more widely the knowledge possessed by those practically acquainted with submarine telegraphy than at announcing the latest discoveries or most novel theories.

1. *Terms used:—Conductor, Insulator, Battery, Earth, Circuit, Current.*—Some elementary explanations were given with the view of explaining these terms. The action of a current on a magnetic needle, the simplest form of galvanometer and electromagnet were shown, with their application to practical telegraphy. The two sources of failure, viz. want of continuity in the conductor and want of insulation forming a short circuit, were explained. The reflecting galvanometer was exhibited as a means of indicating a feeble current.

The following is a more detailed abstract of the rest of the lecture:—

2. *Component parts of Submarine Cable.*—These are:—1st, the conducting wire, generally formed of copper; 2nd, the insulator, surrounding the conductor, generally india-rubber or gutta-percha; 3rd, the outer covering, intended to give strength, and generally formed of a hempen serving, surrounded by iron wires, laid, as in the rope, round and round the core.

3. *Conductor.*—(*a*) *Mechanical Properties.*—The conductor is almost universally made of copper; but a solid copper wire is apt to be brittle, breaking after being bent a few times; interruptions occurred from this cause in early cables: this defect is wholly removed by the use of a strand of several wires, generally three or seven. The tensile strength of copper wire is in some books given as 60,000 lbs. per square inch. That used for submarine cables, being selected for electrical rather than mechanical qualities, will only bear from 35,000 lbs. to 39,000 lbs. per square inch. Copper stretches so much (10, 11, 12, or 15 per cent.) before breaking that its full strength can seldom be made use of. This extensibility is, as will be seen, a very valuable property, preventing the interruption of the circuit until the strengthening part of the cable be fairly broken. The following are convenient approximate formulæ:—A copper strand will bear $1\frac{1}{2}$ lb. per pound weight per knot before breaking; it will stretch one per cent. with 1 lb., and will not stretch at all with 0·75 lb. per pound per knot: thus a strand weighing three hundred pounds per knot will barely support 450 lbs., will stretch one per cent. with 300 lbs., and will not stretch at all with 225 lbs. The weight of copper in lbs. per knot can be calculated from the diameter d in inches by the use of the following constants:—weight$=18500\ d^2$ for solid wire, or $15100\ d^2$ for strand. The joint of the conductor is made with great care: a scarf joint is made by soldering together two filed and fitted ends; this joint is wrapped round with fine copper wire to give it strength, and solder is again run round this wire; a second wrapping of fine copper is then applied and left without solder. The joint is necessarily less extensible than the rest of the strand; if forcibly torn asunder the last wrapping of copper maintains the

APPENDIX B.

he following Table shows the degree of concordance obtained in the sepa- experiments used to determine the unit. The determinations were made bserving the deflections of a certain magnet when a coil revolved at a given d, first in one direction, and then in the opposite direction. The first mn shows the speed in each experiment; the second shows the value of B. A. unit in terms of $10^7 \frac{\text{metres}}{\text{second}}$, as calculated from the single experi- ts. A difference constantly in one direction may be observed in the es obtained when the coil revolved different ways. This difference de- led on a slight bias of the suspending thread in one direction. The third mn shows the value of the B. A. unit calculated from the pair of experi- ts; the fourth shows the error of the pair from the mean value finally ted. In the final mean adopted, the 1864 determination was allowed times the weight allowed to that of 1863.

1. ime of 100 revo- utions of coil, in seconds.	2. Value of B. A. unit in terms of $10^7 \frac{\text{metres}}{\text{second}}$, as calculated from each experiment.	3. Value from mean of each pair of experiments.	4. Percentage error of pair of observations from mean value.
17·54	1·0121	0·9978	−0·22
17·58	0·9836		
77·62	1·0468	1·0040	+0·28
76·17	0·9613		
53·97	0·9985	0·9992	−0·08
54·53	0·9998		
41·76	0·9915	0·9925	−0·75
41·79	0·9936		
54·07	0·9961	0·9924	−0·76
53·78	0·9886		
17·697	0·9878	1·0007	+0·07
17·783	1·0136		
17·81	0·9952	1·0063	+0·63
17·78	1·0174		
17·01	1·0191	1·0043	+0·43
16·89	0·9895		
21·35	1·0034	1·0022	+0·22
21·38	1·0011		
21·362	0·9968	1·0040	+0·40
21·643	1·0096		
11·247	1·0424	0·9981	−0·19
16·737	0·9707		

Probable error of R (1864)........... =0·1 per cent.
Probable error of R (1863)........... =0·24 „
Difference in two values 1864 and 1863 =0·16 „
Probable error of two experiments.... =0·08 „

gradually eaten away, until metallic continuity is interrupted, and the cable ceases to transmit messages. The current from the zinc pole does not produce this effect, but only a deposit of soda in the fault, which, however, this allows a greater leakage, tending to enlarge the hole in the gutta-percha. Mr. C. F. Varley has proposed to twist up a fine platinum wire with the copper strand of long cables. This wire would maintain the communication at any point where the copper might be eaten away.

4. *Insulator.*—(*a*) *Gutta-percha and Chatterton's Compound.*—Gutta-percha is pressed out, while warm and plastic, through a die round the conductor; several successive coatings or tubes are thus applied, till the desired thickness is obtained. The first coating is attached to the strand by a substance known as Chatterton's compound, which is also used between each layer of gutta-percha, and between the separate wires of the strand, to prevent the percolation of water along the interstices, in case any part of the copper should be accidentally immersed in water.

(*b*) *Mechanical Properties.*—Gutta-percha has considerable tensile strength, bearing about 3500 lbs. per square inch of section; but, owing to its great extensibility, it does not add more than about one third of its whole strength to the copper strand. Roughly, it may be said to add in small wires 20 per cent. and in larger cases 30, 40, or even 50 per cent. to the strength of the copper strand; it will stretch 50 or 60 per cent. or more without breaking, but almost always fails as soon as the copper inside gives way. It will bear ill-usage, such as knotting, squeezing, or stretching, without injury, but can be pierced with a sharp instrument or cut by a knife without much difficulty. Uniform pressure, such as it sustains under water, improves its electrical qualities, augmenting its insulation resistance, according to Mr. Siemens's experiments, about 60 per cent., at 24° C., for every ton pressure per square inch, corresponding nearly to 1000 fathoms depth of water. It becomes soft at about 100° Fahrenheit, and should, after manufacture, never be heated beyond 90°. The joints required are made by heating the two ends of the covered conductors after the copper is joined, and applying by hand successive coatings of warmed and plastic gutta-percha. The separate layers of gutta-percha are also cemented by Chatterton's compound; thus the joint is, when sound, very similar to the rest of the core. Extreme cleanliness and much skill are required in making these joints. Some years since the joints frequently failed, not always when just made, but after some months, becoming hard and brittle, and shrinking, so as to leave a gap between the old and new materials. The process is now thoroughly understood, and is a safe one in skilled hands, but in skilled hands only.

(*c*) *India-rubber.*—This material is applied in many ways; most commonly tapes of masticated or bottle-rubber are wrapped round and round the conductor until the required thickness is reached. At first these tapes were, as it might be termed, gummed together with solvents; but these caused decay, and have been abandoned: heat is now the common agent for effecting the adhesion. Mr. Siemens, who applied his tapes longitudinally, like two long half-tubes, used simple pressure to join the two halves together. He employed most ingenious machinery to cut the tapes the instant before they were applied to the copper, as the material only reunites if quite freshly cut; several successive coatings could be applied in this way at one operation. Some manufacturers considered that none of these methods were fully successful, and vulcanised the india-rubber, converting it into various materials of different degrees of flexibility according to the process employed. This material was also [illegible] and Mr. Hooper has covered conductors with

Part 1.—Cables.

(*The Specifications are given at the end of the Abstract of this Lecture.*)

Cables.	Breaking-strain in cwts.	Corresponding length in water. Fathoms.	Per cent. of elongation with one half breaking-weight per cent.	Per cent. of elongation with breaking-weight per cent.	Weight per knot in air. cwts.	Weight per knot in water. cwts.	Remarks and authorities.
1st Atlantic	80	4,979	0·24	0·8	21·70	16·30	Report of Joint Committee, App. 10.
Red Sea....................	65 to 87·5	3,806 to 5,112	0·16 to 0·34	0·56 to 1·16	21	17·30	Ditto.
Malta-Alexandria	147 „ 157	4,565 „ 4,874	0·2 „ 0·36	0·5 „ 0·86	42·70	32·73	Ditto.
2nd Atlantic	154	11,000	......	2·57 „ 4·65	35·75	14·0	Unpublished experiments by Mr. Fairbairn.
Steel - and - Hemp-coated Gibraltar	102·5 „ 147·5	7,928 „ 11,407	0·62 to 1·24	1·87 „ 4·06	25·47	13·11	Report of Joint Committee, App. 10.
Iron-and-Hemp-coated	67·5 „ 75	5,346 „ 6,000	0·26 „ 0·77	1·80 „ 3·10	24·87	12·65	Ditto.
Siemens's Copper-covered Cable	50	6,250	......	0·8	18·61	7·97	Mr. C. W. Siemens's unpublished information.
Allan's Cable............	18·37	7,500	......	1·0	8·0	2·5	Mr. Allan's unpublished information.
Ratan and Stretched Hemp...............	15·75	8,500	0·52	1·56	7·73	1·86	Messrs. Forde and Jenkin's unpublished information.

Part 2.—Materials.

Copper strand, Malta-Alexandria............	5·75	......	0·22	8·5	3·57	3·125	Report of Joint Committee, Appendix 10.
Core, Malta-Alex.......	5·75 to 7·5	2,260 to 2,826	0·28	22 to 25	7·15	3·36	Ditto.
*Iron Wire, 0·079 in.	4·18 „ 4·5	5,600 „ 6,040	0·12 to 0·18	0·46 „ 0·72	96 lbs.	83·5	„
*Steel Wire, 0·079 in.	8·00 „ 8·50	10,600 „ 11,200	0·28 „ 0·34	1·00 „ 1·80	97 lbs.	84·7	„
Hemp and Iron	5·00 „ 7·43	......	0·16 „ 0·32	1·04 „ 2·46	141 lbs.	......	„
Steel and Hemp	10·87 „ 11·75	......	0·37 „ 0·51	2·28 „ 2·70	142 lbs.	......	„
Hemp alone	2·87	......	......	......	45 lbs.	......	„

* Other specimens of iron and steel would be found to stretch differently. Some iron and some steel would stretch considerably more, and very hard would stretch less. The above results seem to be taken from fair samples.

side for eighteen inches of its length. This proved that the iron wires not press injuriously on the core. In all these experiments the rope w free to untwist, but did not do so sensibly. The experiments were sim illustrations of facts well known to all practically acquainted with telegrap cables. It may therefore be assumed that the common form of cable is n liable to stretch; but another defect, the liability to kink, has been urg against it. A kink is a loop drawn tight, or a twist in a rope concentrat at one point. Specimens of kinks were shown. A kink may be produced i any form of cable, with or without helical covering, inasmuch as a loop or a twist may be produced in any form by mismanagement. A rope coiled round a drum with one side out may be wound off and rolled round another drum, or paid out into the sea, without receiving any twist; but if, by mismanagement, the rope were pulled off the end of the drum, it would be twisted or kinked. Similarly, if coiled in a tank, with one side always uppermost, although apparently without twist, it would be twisted or kinked when pulled straight out of the hold. In practice these plans are not adopted; the cable is carried down into tanks from a drum with one side always turned in one direction: let one side of a straight cable be marked black, and let it be coiled into the hold so that the black side shall always be north, then this black mark will, on the north side of the tank, be turned from the centre; at the east and west side it will be uppermost and undermost respectively. The rope thus coiled in will have one twist in it for every turn round the tank: in a spun rope this twist will twist the rope tighter, or untwist it according to the direction in which the rope is coiled; but, in either case, when the rope is drawn out of the coil it comes out as it was put it—straight and without twist. The extra turn or twist is caused by coiling, and removed by uncoiling. There is one simple, universal, and sufficient rule to prevent the occurrence of a permanent twist. The cable must be taken out of the tank or off the drum in the same manner as it is put in or on; the opposite course will always put a permanent twist into a cable, and this twist, concentrated at one point, produces a kink. These points were illustrated by elementary experiments with a piece of india-rubber tubing to represent a cable; one side of the tube was painted so that a twist could readily be seen. When a cable is properly coiled in the tank it is possible, by a severe jerk, so to mismanage the uncoiling as not to take out the twist regularly; and kinks have thus been caused by several turns being caught up at once out of the hold. This now very seldom happens. Not one kink occurred during the paying out of the Malta-Alexandria and Persian-Gulf cables, or during the late Atlantic expedition, in all about 3500 knots. Even when a kink does occur it seldom injures the cable. A specimen was shown, cut from the Dover and Calais cable, containing six insulated wires, through which, kinked as they were, messages had for years been transmitted between England and France. The common form of cables affords a good mechanical protection against injury.

3. *Iron and Steel Wire.*—The tensile strength of a cable is the sum of the strength of the wires composing it. A cable covered with good iron should bear a strain equal to two tons per pound of iron wire per fathom. Thus a cable with 3750 lbs. of iron per knot, or 3·75 lbs. per fathom, in the sheathing should bear 7½ tons. This rule corresponds to a strength of about 41 tons per square inch. The larger gauges and inferior qualities of iron cannot be expected to bear so high a strain as this. Best best is the quality most usually specified; but charcoal wire seems to be more permanent than the rior brands. The wire should in no case be hard or brittle. Bright

but protection, where possible, should always be given. Bright and Cla silicated bituminous compound applied over the wires affords the best p tection yet known. The Persian-Gulf Cable is coated with it from end end. To ensure permanency, cables in shallow seas were now laid weigh as much as ten tons per mile, with shore ends weighing nearly twenty t to resist anchors (*vide* England-Holland Cables, Appendix). Many hea shore ends were covered with strands of wire instead of simple wires. Siemens proposed to apply a covering of hemp outside the iron wires and wrap this round with a zinc armour.

6. *Statistics of Cables in Shallow Seas.*—The total failures of all kinds, shallow water, excluding the cables which had no proper outer iron protecti did not amount to 100 miles. About 2350 miles have been laid, whi worked for some time, but are now abandoned. Of these, 1400 miles weigh less than one ton per mile, a weight which, for shallow seas, is n known to be absurdly insufficient; these worked for about two years upon average. 950 miles weighed more than one ton, but not more than two to per mile: the average life of these cables was five years. 5000 miles now certainly at work, possibly more; they have already worked upon average four years and a half: they include one cable which has worked 15 years, and several 13 years old; but the average is lowered by the lo Malta-Alexandria and Persian-Gulf cables, only lately laid. Every one these cables, except the Malta-Alexandria, not originally designed for shall seas, weigh more than two tons per mile. The interruptions on the light cables are somewhat frequent: on the Malta-Alexandria they have averag four days per 100 miles per annum; even this is not worse than the be land-lines in India, and is ten times better than the worst land-lines India.

7. *Maintenance and Returns from Cables in Shallow Seas.*—The average co of maintaining cables of the Submarine and Electric Telegraph Companies h been for some years from £8 to £9 per mile, excluding the cost of total renewa which should be provided for by a reserve fund. The expense of the Malt Alexandria repairs is not known. This line has earned as much as £300 in one week, or at the rate of £117 per knot per annum. In one year th average earnings during the time it was open were at the rate of more tha £90,000, or £68 per knot per annum; allowing for interruptions, the maxi mum earnings in one year were £64,000, or £48 per knot. The Persia Gulf cable is said to be earning at the rate of more than £100,000 per annu or £85 per knot per annum. Neither cable has yet worked under favou able conditions; the former ends in a *cul-de-sac*, and the land-lines co nected with the latter are so badly worked as to cause extreme delay an uncertainty. Such cables can be laid for sums varying from £300 to £40 per knot. The receipts on the Submarine Company's lines seem lately t have been at the rate of about £85 per knot of cable, or £26 per knot insulated wire.

8. *Deep-Sea Cables.*—Cables laid in less than 1000 fathoms would now hardly be considered deep-sea cables; but formerly a depth of 300 or 400 fathoms was thought sufficient to entitle a cable to be put in this class, and the old classification has been adhered to in preparing the statistics of shallow-sea cables. A cable to be laid in a deep sea must, of course, be strong both absolutely and relatively to its weight in water; it must be light, or the great lengths required cannot be conveniently carried; it must not be liable to stretch, and it must coil well and be paid out easily. At first, light specimens of the form already described as used for shallow seas were generally

TABLE VI.

led from App. 10 to the Report of the Joint Committee on Submarine Cables (Gisborne, Forde, and Siemens).

Materials.	Breaking-strain, cwts.			Elongation in percentage of length.			
	Max.	Min.	Mean.	Max.	Min.	Mean.	No. of Experiments.
0·073 in. diameter	8·50	8·00	8·20	1·80	1·00	1·41	5
0·073 in. diameter	4·50	4·18	4·35	0·72	0·46	0·55	7
with 4 strands illa hemp .... ¾ in. lay 1½ in. lay	9·25 13·00	9·25 12·12	9·25 12·59	1·77 3·12	1·77 2·32	1·77 2·63	3 6
with 4 strands ian hemp .... ¾ in. lay 1½ in. lay	10·0 11·75	9·50 10·87	9·70 11·42	2·18 2·70	1·80 2·28	1·76 2·45	3 5
with 4 strands illa hemp .... ¾ in. lay 1½ in. lay	4·75 8·50	4·50 8·12	4·62 8·28	0·79 2·80	0·47 2·56	0·63 2·62	3 4
with 4 strands ian hemp .... ¾ in. lay 1½ in. lay	5·00 7·43	4·75 5·00	4·87 6·20	0·92 2·46	0·66 1·04	0·82 1·82	3 6
emp weighing 0·05 lb. to lb. per fathom	3·87	3·62	3·75	...	...	2·62	2
emp weighing 0·41 lb. to per fathom	3·50	2·25	2·87	1·60	1·00	1·30	2

d. The Red-Sea cable is a fair sample. The first Atlantic cable is
nilar; but the simple outer wires were replaced by strands of still
wires. The examination of Table IV. will show how far these cables
above requirements. They could support from 4000 fathoms to
thoms of themselves hanging vertically from the ship. They could
, and about 7000 miles of this class were laid, in depths ap-
ng or exceeding 2000 fathoms; and these cables have even, for a
es, been hauled back from these depths. They seldom broke while
aid, but they were not permanently successful. Communication
y ended within a year from the time it was established, and the
overing was then too much rusted to allow of repairs. The
f failure were many,—bad gutta-percha joints, bad copper joints,
to the insulator before the cable was laid, high battery-power burn-
ll faults into big ones and eating away the copper; lightning, from
ey were often unprotected. These may be instanced as known causes
e. It is also said some cables were laid too light, and sprung asunder
e iron wires rusted. It may be conjectured that when these wires
he gutta-percha could not bear the cable if suspended across a hollow;
e less probable causes of failure, but it is certain that the rusting of
ide and the failure of the cable generally coincided as to time. The
was seldom gradual; it was almost, if not always, accompanied by a
cture or interruption in the copper. When any of these injuries
r they were irremediable. The first important modification of the
form was to adopt steel wires instead of iron, reducing their number,
eloping them in hempen strands, so as to produce a cable which ex-

ternally looks like a hempen rope. Many excellent experiments were
on this form of cable (which was subsequently chosen for the second Atl
by Messrs. Gisborne and Forde, aided by Mr. Siemens. These experi
are given in full in Appendix 10 to the 'Report of the Joint Committe
the Construction of Submarine Cables,' published by government in
The great strength, both absolute and relative, of this form may be
from Table IV., showing that these hemp and steel cables will su
11000 fathoms of themselves hanging vertically in water. The m
steel required to cover the core is diminished by the use of hemp; b
hemp is no lighter than water, it does not buoy up the wire. A steel
simply wrapped up in hemp weighs much the same in water as a bare
and therefore wires, whether simply wrapped in hemp or bare, will su
equal lengths of themselves in water; but the hemp may be so applied
add all its strength to that of the steel, although the extensibility of th
materials is different. To do this the hemp must be spun round the steel
a definite lay, to be ascertained in each case by experiment. Table VI.
the strength of iron and steel strands wrapped with Russian and M
hemp, and with $\frac{3}{4}$ lay and $1\frac{1}{4}$ lay respectively; also the strength and s
of the separate materials. It will at once be seen that a difference
produces an extraordinary augmentation in the breaking-strain and i
elongation. The stretch of a wire when approaching its breaking-str
concentrated nearly at one point, where it rapidly diminishes in dia
The effect of the hemp is to support the wire at a number of successive
spots of this kind, and thus greatly to augment the elongation before
ing; but it will further be observed that the breaking-strain of the com
materials is actually greater in some cases than the sum of the streng
the separate materials. Thus the sum of the Manilla and steel, taki
mean strength, is a little less than 12 cwt.; but the mean of the com
strand is more than $12\frac{1}{2}$ cwt. With Russian hemp the sum of the se
strengths is 11·07 cwt., but the combined strand supported 11·42 cwt.
results with iron do not show this anomaly; but the apparent parado
steel wire has been fully confirmed by independent experiments ma
the Atlantic Telegraph Company. The explanation is, that when
separately we have the strength of the weakest points or smallest s
of the wires and strands; but these materials are never uniform, and
combined, as it is most improbable that the two weakest points should
cide, we obtain the sum of their mean sections or strengths. The
formed by these hemp-covered steel wires are very strong. Table IV.
that the Atlantic cable, relatively and absolutely, is the strongest cab
made, bearing more than twice as great a length of itself as the ol
cable. The new form stretches more than the old. The hemp may be
off or decay from the wires, weakening the cable, and the hemp affor
mechanical protection against injury; but the stretch is never such
endanger the core, as has been proved by repeated experiments, and th
serious defect of the cable is probably its expense.

9. *Proposed forms of Deep-Sea Cables.*—Rowett's hempen rope coul
tainly be laid. The lecturer has had no sample of it, but fears it wo
extensible. Allan's cable could also be easily laid, so far as its stren
concerned. It is said to coil badly; but the lecturer has not see
tested. The proximity of the copper and steel inside the cable might
the steel to rust and burst the core. Still it is desirable that this
should be practically tested. Mr. Siemans's cable, also mentioned in
IV., will be found described in the Appendix to this lecture. The str

p has great strength and elongates little, but has to carry an immense
of copper, which does not add to the strength of the cable. The phos-
tized copper sheathing would probably be very permanent. This cable
actually been laid and is now working. A trial of it was not successful
leep water, but a piece was recovered from 1600 fathoms. Duncan's
e, covered with plaited ratan, is too extensible; and the ratan, though
ble in water, does not add much tensile strength. The lecturer has had
mple of cable made, in which he used Siemens's stretched hemp covered
Duncan's plaited cane. Its properties are given in Table IV., and its
ifications in the Appendix. This cable combines great strength, small
gation, lightness, and cheapness. A bare gutta-percha core could be
easily, but could not be recovered from great depths.

). *Statistics of Deep-Sea Cables.*—Excluding the 1000 miles in abeyance
r the Atlantic, and the cable lost in the first experimental trips in the
ntic, only some 500 or 600 miles of cable have been lost during laying.
ut 9000 miles have been laid and worked a little while, but are no
er working. From 700 to 850 miles are now at work; but much of this
no great depth. The Barcelona Mahon cable, believed still to work,
ough faulty, is included in this list. There is but one quite sound cable
g at work in more than 1000 fathoms, viz. that between Sardinia and
y, 243 miles long. One section of the Malta-Alexandria cable is in
fathoms, and has never shown any deterioration. The probable causes
ilure have already been enumerated.

l. The general conclusions to be drawn from the statistics given in this
ire seem to be:—that in shallow seas, by laying heavy strong cables, we
ensure, and have obtained, success, both from an engineering and com-
cial point of view; that in deep seas we have hitherto failed, but that
ess is not unattainable, and may probably be reached by various methods.
lecturer believes that while in shallow seas, where repairs are possible,
es can hardly be laid too heavy or at too great an expense, in deep seas,
re repairs will always be precarious, they can hardly be laid too light or
heap.

APPENDIX I.—*Specification of Cables in Tables.*

. First Atlantic.—Core (*vide* Table III., p. 205) covered with 18 strands
bright best charcoal wires 0·028 in. diameter, called No. 22. Total
neter 0·62 in.; weight of iron 15·64 cwt. per knot.

. Red Sea.—Core (*vide* Table III.) covered with 18 bright iron wires
iarcoal), called No. 16, B.W.G.; diameter 0·077. Total diameter 0·56
weight of iron 16 cwt. per knot.

. Malta-Alexandria.—Core (*vide* Table III.) covered with 18 bright
coal iron wires, each 0·12 in. diameter, called No. 11 (?). Whole cable
in. diameter; weight of iron 33·56 cwt. per knot.

. Persian-Gulf.—Core (*vide* Table III.) covered with 12 galvanized iron
s, 0·18 in. diameter, called No. $7\frac{1}{2}$ (?); diameter of iron cable 0·9 in.;
red with hemp and bituminous compound to 1·25 in. diameter; weight
knot of completed cable 3·7 tons.

. England-Holland main cable.—10 black wires 0·375 in. diameter, called
00; external diameter 1·58 in.; weight per knot 10·4 tons: shore end
vires, 0·22, *called No. 5;* covered with 12 strands made of 3 wires of

TABLE VIII.

Showing the length of a catenary curve of constant span = 100, with various deflections at the centre, and giving strains at highest point in terms of the unit length of chain.

Proportion of versine to span.	Length of versine or dip.	Length of curve.	Strain at highest point in terms of the unit length of chain.
0	0·00	100·0	infinite
$\frac{1}{12}$	8·33	102·1	160·9
$\frac{1}{11}$	9·09	102·6	149·3
$\frac{1}{10}$	10·00	103·0	137·6
$\frac{1}{9}$	11·11	103·4	125·8
$\frac{1}{8}$	12·50	104·3	115·2
$\frac{1}{7}$	14·29	105·4	104·3
$\frac{1}{6·5}$	15·38	106·4	99·7
$\frac{1}{6}$	16·67	107·3	94·5
$\frac{1}{5·5}$	18·18	108·9	90·5
$\frac{1}{5}$	20·00	110·4	86·2
$\frac{1}{4·5}$	22·22	112·4	82·1
$\frac{1}{4}$	25·00	115·4	79·1
$\frac{1}{3}$	33·33	125·4	75·6
$\frac{1}{2}$	50·00	177·3	103·5

of trying to raise a cable such as the Atlantic laid taut would certainly be to break it; but cables are not laid taut in deep water, and the Atlantic is laid with a mean slack of about 12 per cent., and in the last days we may even count on 14 or 15 per cent. slack—that is to say, for every 100 miles passed over, 114 or 115 miles of cable were laid. Lay on the floor 114 inches of chain, between two points 100 inches apart; lift it in the middle on a hook, the two ends will hang down in catenary curves; and when the cable at the extremities is just off the floor, the hook will be 23·3 inches from the floor. Quite similarly a cable laid with 14 per cent. slack will, when caught by the grapnel, hang in two half catenary curves; and by the time 11·4 miles of the cable are off the ground, the grapnel will be 2330 fathoms from from the bottom, *i.e.* at the surface of the Atlantic. The strain on the grapnel-rope will be the weight of the cable lifted, or about 12·4 miles; the strain on the cable itself at the point of suspension will be much less, being only about 3½ times the weight of the cable hanging vertically, or say 8 miles of cable. (Observe that the strain on the cable and the weight of the cable are not synonymous. When the two ends hang plumb, the strain on the cable at top is half the weight of the cable carried. When there is little slack, the strain is much greater than the weight carried.) If the depth were only 2000 fathoms, the strain on the cable when brought to the surface would only be equal to the weight of about 7 miles of cable. Moreover, the actual cable is not held at any point except by its own weight, and there will be a pull at the bottom tending to haul in slack towards the grapnel amounting to several tons: but, even without counting upon slack obtained *in this way*, it is clear that if the cable will bear 11 miles of its own weight, it could, under favourable circumstances, be hauled to the surface by a single grapnel.

Tables VII. and VIII. give the proportions and strains on catenaries in various convenient practical forms. Thus, from Table VII. we see that if ten per cent. slack be laid, the maximum tension on the catenary lifted in, say one mile, will be the weight of 4·52 miles of cable; in two miles depth the strain would be the weight of 9·4 miles of cable. In the latter case, 2 × 5·67 = 11·34 miles of cable will be off the ground, and the grapnel-rope must be strong enough to bear this. Table VIII. gives similar information, supposing we do not start from a definite percentage of slack, but know the proportion of the dip made by a rope to the strain. But although from these tables it appears that the Atlantic cable might be lifted by sheer pulling, this course is not advisable, owing to the extra strains produced by the heave of the ship, the resistance to displacement by the water, the friction of the water, possible currents of water, the possible drift of the ship to one side of the cable, and the possible existence of a weak point in the cable. Owing to all these elements the practical chances of success by sheer pulling are very small. It has been proposed to lift the cable by a number of ships, acting like so many piers to a suspension-bridge. It is difficult to suppose that they would keep their respective positions accurately, or all haul in at the proper rate. It has also been proposed to catch the cable at one point, then at another nearer the end, then to drop the first grapnel, and catch the cable again nearer the end, and so, working hand over hand, reach a point at last so near the end that the cable could be lifted nearly vertically. This is better than the last plan, but is unnecessarily complicated, and the cable might easily be injured in the attempts to catch it at so many points. The simple plan which at once occurred to all practical men, is to catch the cable with one ship by a holding-grapnel, and then to cut it with a grapnel from a second ship, some three miles to seaward; the loose end held by the first ship could then be hauled on board with little strain. This plan will probably be adopted, with much chance of success. It is certain the cable *was* caught, and probably it can be hooked again; if so, there should be no difficulty in raising it, unless it is rusted to a much greater extent than we have any reason to expect. The grapnel of the first ship should be a holding-grapnel, of which several models were shown, otherwise the loose end might fly back over it if the second ship cut too near the first. The second ship should have a cutting-grapnel, of which models were also shown, lest if the attempt were made to break the cable by brute force it might break at an inconvenient point. Mr. Latimer Clark's grapnel, which would answer either of these purposes, was exhibited. The cable when hooked releases a catch, allowing a block, to which the grapnel-rope is attached, to be hauled up the shank, pulling round two right and left hand screws by two steel bands; the screws close the jaws, which grip the cable or cut it; or one grapnel may be made both to cut and grip the cable. The grapnel can lie in only two positions; and if dragged in the proper direction, cutters placed at two diagonally opposed corners would cut the cable certainly to seaward, and the jaws hold the landward end. A simple form of holding-grapnel, conceived by Mr. Carpmael, jun., was shown; in this the cable is jammed between the prongs and a kind of half bollard. A holdfast or cutting-grapnel, designed by the lecturer, was also shown. Each prong is hinged on a pin projecting beyond the shank, and the prong is so shaped at the root that the cable when on it closes the prong tighter and tighter on itself, whereas the end of the prong when dragging through sand or mud is opened like a Trotman's anchor.

do not sensibly vary. This arrangement was used on the 'Great Eastern It worked admirably, and gives a perfect safeguard against the applicatio of any unforeseen strain by the friction of the break-strap. Strains may, how ever, occur from other causes, and for their detection a dynamometer is use between the break and the stern. The cable is passed under a weight pulley, at a somewhat obtuse angle. The weight thus hanging on the cab is raised higher and higher as the strain on the cable increases. A scale i constructed by experiment showing the height corresponding to each strain By this simple contrivance the actual strain on the cable can be observed any moment. The following is a convenient formula for calculating the re lation between the strains on break-straps and the friction produced. Let Q be the strain on that end of the strap which holds back the wheel, P the strain on the other end, f coefficient of friction, and b the angle embraced by the strap in circular measurement (unit $=57{\cdot}296°$).

Then $Q=e^{fb}P$, where $e=2{\cdot}71828$.

f may be taken for leather on iron .... $=0{\cdot}35$
" " iron on iron, wet ...... $=0{\cdot}15$
" " wood on iron, wet, less than $0{\cdot}1$

3. *Theory of Submersion.*—In October 1857, Professor William Thomson published in the 'Engineer' a short sketch of the true mathematical theory of the form assumed by a cable while sinking, and the strains to which it is subjected under various conditions. The consequences of this theory were much more elaborately worked out (independently of Professor Thomson's publication, the lecturer believes) by Messrs. Brook and Longridge, in a paper read before the Institution of Civil Engineers in the spring of 1858. Much of what follows is taken from that paper. If the ship and cable are both a rest in still water, the latter hangs in a catenary curve, the strains on whic are known and easily computed. This case actually occurs whenever a shi stops paying out cable, for instance, to cut out a fault: if the cable wer suddenly stopped so as to lie at a great angle with the vertical line, a strai would be produced so great as infallibly to break the cable; thus, for a cate nary in which the cable at the point of suspension lies at an angle of 9° 3 with the horizon, the strain at the point of suspension is equal to 72½ time the weight of the cable hanging to the same depth vertically; so that in 200 fathoms the strain would be equal to the weight of 145 miles of cable; bu the Atlantic cable would break as soon as the strain exceeded the weight 11 miles. From this it will be seen that a cable cannot be immediatel stopped whilst being paid out, but must be gradually checked while the shi is backed, so as to keep the cable where entering the water as nearly vertic as possible. Another conclusion which follows is, that the cable while bein paid out cannot possibly be hanging in a catenary curve, since the Atlanti cable did lie at an angle of about 9° 30′, and the strain, instead of bein 2030 cwt., was only about 12 cwt. The following consideration may hel us to perceive how different the case of a body sinking regularly is from th case of a chain at rest. Suppose the ship to drop a number of spheres the specific gravity of the cable into the water at regular intervals; each these would, within about two feet of the surface, acquire a definite, sensibl constant velocity $v=\sqrt{\frac{w}{q}}$, where $w=$ the weight and q the resistance the body moving at one foot per second; these spheres, moving with consta velocity at constant intervals of time, would lie in a straight line from th surface to the bottom, and would be more or less inclined to the horizon

speed of the ship was less or greater. If the spheres were joined by an itely thin string, to which the water offered no resistance, they would a cable which could be laid without any tension whatever, and with an unt of slack or waste depending simply on the inclination of the line to horizon. The practical case of a submarine cable lies between these two emes of the catenary and the isolated spheres; each short length of the e lies like an inclined rod in the water, and has, therefore, a tendency to ot back in a given direction, whereas the isolated spheres tend to fall vertilly. Owing to this, cables, or, at least, heavy cables, cannot be laid with- tension except at the expense of an enormous waste of cable. It will be ecessary here to repeat the whole mathematical investigation which is en in Messrs. Brook and Longridge's paper. It will be sufficient to give results arrived at. Mathematical readers will readily understand that se results are calculable from the data given :—

v=the velocity of the paying-out vessel in feet per second.

v_1=the velocity of the cable paid out in feet per second.

w=the weight of one foot length of the cable in lbs.

ϕ=the angle which the cable at the surface makes with a horizontal line.

x=the height of any point A from the bottom of the sea.

q=the resistance in lbs. which the water opposes to the motion of each t of the cable moving perpendicularly to itself, at the speed of one foot second; q may be called the coefficient of resistance to displacement.

q_1=the resistance in lbs. which the water opposes to the motion of each t of the cable drawn through it lengthways, at the speed of one foot per ond; q_1 may be called the coefficient of friction.

m=the resistance in lbs. which the water opposes to the motion of each of the cable moving perpendicularly to itself, at the speed of v feet per ond; m is assumed $=qv^2$.

m_1=the resistance in lbs. which the water opposes to the motion of each of the cable drawn through it lengthwise at the speed v; m_1 is assumed $q_1 v^2$.

=tension in lbs. at point A, which in what follows will be assumed as at surface, where the maximum strain occurs.

Then if the cable be laid without any tension at the bottom, which is now ariably done, the equation to the curve assumed by the cable will become equation to a straight line inclined at an angle to the horizon such that

$$\cos\phi=\frac{\sqrt{w^2+4m^2}-w}{2m}\,. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

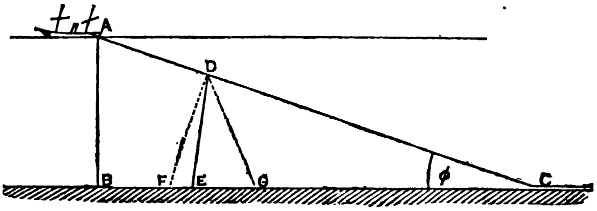
what amounts to the same,

$$\frac{\cos\phi}{\sin^2\phi}=\frac{qv^2}{w}\,. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

om this it appears that the angle at which any given cable will be paid is (when not tight at bottom) independent of the tension t (or of the ocity v_1), and is dependent simply on the velocity v of the ship. Cables ich are bulky for their weight, or, in other words, are of light specific vity, lie at a small angle; but by increasing the ship's speed any cable y be paid out at a small angle. We find further, when no slack is paid ,

$$t=\left(w-m^1\frac{(1-\cos\phi)^2}{\sin\phi}\right)x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3$$

$w\,x$ is simply the weight of a length of the cable hanging plumb from tl ship to the bottom. This is the maximum tension that can be required lay any cable without slack. This tension is always slightly diminished l a certain small portion of its amount, constant for a given speed and cab The annexed diagram may help to explain the results arrived at. The cal A C, lying on an inclined plane of water at the angle ϕ, is carried by a te



sion equal to the weight of a length A B of cable, somewhat as a chain w be in equilibrium lying on a frictionless inclined plane A C, and hang down over a pulley at A to the depth B; but the inclined plane of wat not at rest; it yields under the cable at every instant at every spot: if cable were pressed through the water in a direction perpendicular to it so that the plane of water yielded before the pressure of the cable, and not slip along it at all, the above analogy would be perfect, and the ten at A would be simply equal to $w\,x$; but since we have supposed the c to be laid without tension, and without slack at the bottom, any poi must finally come to a point E, such that E C = D C; and it will be ea seen that the point D to do this must move in a straight line E D. Now line D E is not perpendicular to A C; it falls within that perpendicular, l so that if we suppose the plane of water under A C to yield perpendicul before it, we must also conceive the cable as slipping back a little on plane by an amount corresponding to the space between D F and D E; this slip is opposed by the friction of the water, which thus tends to pre the cable from running back on the inclined plane, and so relieves the ten by a small amount. This amount is so small that it may be practically n lected, and would not have been mentioned did not the same considerat enable us to understand the effect of laying cable with a certain amou slack. When this is done a point, D, moves in a line, say D G, diffe much more in direction from D F than D E does. When much slack is l the cable slips back at a considerable velocity on the inclined plane, meets with a frictional resistance tending considerably to relieve the tens Thus, when the cable is paid out at a velocity v_1, we have

$$t = \left[w - m^1 \frac{\left(\frac{v^1}{v} \cos\phi \right)^2}{\sin\phi} \right] x. \quad . \quad . \quad . \quad . \quad . \quad . \quad .$$

When v_1 is considerably in excess of v, the fraction of the whole tens which the friction m^1 subtracts from $w\,x$ is very considerable. It also creases rapidly as the speed of the ship increases, and it further increase the specific gravity of the cable be small; for then it lies at great lengtl the water, presenting an immense surface to be gripped by the water. ' friction on each foot is but small; but when twelve or thirteen miles of ca lie in the water, presenting a surface of 70,000 or 80,000 square feet, result is practically very important. Assuming a mean speed of 10·4 per second as that at which the Atlantic cable was paid out when lying at an angle of 9° 30′ in 2000 fathoms of water, with a tension of 12 cwt., we obtain the following values for the constants:—

$$\left.\begin{aligned} q &= 0{\cdot}085 = 0{\cdot}81\ D \\ q_1 &= 0{\cdot}0085 = 0{\cdot}081\ D \end{aligned}\right\} \text{where } D = \text{diameter of cable in feet.}$$

From some observations it would seem as if the angle had been even less than the above, in which case q would be larger and q_1 smaller. From Beaufoy's experiments we should have expected q to be more nearly 0·65 D; but the roughness of the cable may account for the difference, as it certainly does for the great difference in the coefficient of friction, which is nearly eight times that which a smooth surface would present. It is probable that for a smooth iron cable the value of q_1 would be more nearly equal to 0·001 D, and $q = 0{\cdot}065$ D. One reason will now be plain for giving in the foregoing tables the strength of the various cables relatively to the depth in which they are to be laid. The strain required to lay them is always a fraction of that depth; but the strain will not be always the same fraction of the depth, but will be smaller for the lighter cables when laid slack.

4. *Application of Theory.*—The practical results of equation (4) are most important. To lay any cable, however light, quite taut, we require nearly the tension due to a weight of the cable hanging plumb from the surface to the bottom; but by increasing the bulk of any cable, though we do not diminish its actual weight, we may, by laying a little slack, diminish the tension very greatly. With such a cable as the second Atlantic the tension was thus diminished more than half; to lay it taut would have required nearly 28 cwt., and 12 cwt. was the amount actually required when about 15 per cent. slack was paid out. The strain could be maintained constant in all depths by allowing a little more slack to run out in deep water, and even this could be prevented by a slight increase in the speed of the ship. No relief at all comparable to the above is obtained by paying out heavy cables slack; but, on the other hand, still lighter cables can be paid out under still more favourable conditions. The ratan and hemp cable (No. 11, Appendix I.) would, with 12 per cent. slack, be paid out without any strain at all; and if more slack than this were desired the cable would have to be pushed out of the ship. Nearly the same might be said of a bare gutta-percha wire. The Atlantic cable, in the last expedition, was laid in depths varying from 1750 to 2000 fathoms, at speeds for the ship varying from 4¾ to 6¾ knots per hour, while the cable ran out at from 5 to nearly 8 knots per hour. The angle, according to one method of observation, varied from 9° to nearly 12°, but was somewhat less according to other observations; 9° 30′ seems to have been a usual angle. The slack paid out in deep water ranged from 9 per cent. to about 18½ per cent. On the last day the slack was about 14·8 per cent. The strain on the cable was very constant, ranging from 10 cwt. to 14 cwt., and generally being between 11 cwt. and 13 cwt.: the pitching of the ship never caused more than about 2 cwt. difference in the strain; but once, when going slow to change holds, the strain was 17 cwt.; this accords with theory. The lecturer has to thank the engineers of the Telegraph Construction and Maintenance Company for the above information.

5. *Proposed Improvements.*—Reels have been proposed in ships as a substitute for the coils in tanks. Their great mass in motion would be difficult to control. Mr. Siemens actually tried with some success a reel for a light cable and drove it with an engine; he abandoned the plan for the old system. The defects which the reel is supposed to remedy do not exist

Captain Selwyn has proposed to use a reel floating in the sea, ingeniously retarded by paddles, which would prevent too much slack from being laid. It hardly becomes a landsman to tell a sailor that such a reel would be unmanageable; but the difficulties of coiling in water, of launching the reel if coiled on land, of protecting the surface of the cable against collisions, of testing the cable, of remedying any defect, should any arise, and even of preventing one coil from cutting into those immediately below it seem unavoidable, and the defects the invention is supposed to remedy are imaginary. Buoys have been proposed to relieve the cable from part of its weight; any hollow buoys would be crushed very shortly after leaving the surface. Mere wooden floats would do little, and be difficult of attachment. This invention also labours under the disadvantage of being unnecessary, since cables can be paid out with 12 cwt. strain or less, which will bear 150 cwt. Vanes on a cable, opposing its slipping backwards, would be correct in principle, although probably quite impracticable; the result aimed at is obtained by increasing and roughening the surface of the cable. Most engineers who have had practical experience deprecate any attempt to catch the cable by nippers after it has left the ship. The danger of fouling is more considerable than the extra chance of safety given by the nipper. Lastly, many proposals have been made for some kind of elastic arrangement, to compensate for the change of strain caused by the rise and fall of the ship. When cables are paid out so nearly horizontally as is now the case, these arrangements, even if practicable, are not required; the alteration of the strain caused by the motion of the ship is quite inconsiderable, and there is great difficulty in devising any elastic arrangement which, by the inertia or momentum of its parts, would not aggravate the evil, such as it is. Unless when going very slow, in very bad weather, the best conceivable elastic arrangement would be useless, if not injurious.

6. *Repairs in shallow water.*—So long as the outer wires of a cable remain sound, repairs in shallow water are always easily effected. The cable is caught by a grapnel, lifted to the surface, cut, tested; and if the fault be near at hand, one end of the cable is buoyed, the other end passed round a drum driven by a steam-engine, which gradually hauls in the cable till the fault is found, when it is repaired, the cable again paid out, and spliced at the part buoyed. Bad weather and a rocky bottom are the chief difficulties to be contended with. Sometimes the cable is not cut or hauled on board, but simply underrun, passing over a grapnel or sheave hung outside the bows of the ship; as the ship moves forward the cable rises in front and is again lowered behind the ship. There are many points of practical interest connected with repairs in shallow water, and the lecturer refers those who require further details to Mr. F. C. Webb's paper in the 'Transactions of the Institution of Civil Engineers,' 1857–58. If the bottom be good, *i.e.* sandy or muddy, cables can always be recovered within 100 fathoms, and they are frequently hauled up in much greater depths.

7. *Repairs in deep seas.*—The only method hitherto practised with success has been to commence in shallow water and gradually haul the cable on board as described above. By carefully keeping the cable hanging vertically from the bows the strain on it will not greatly exceed in calm weather the weight of the cable hanging plumb from the ship. Cables have been recovered in this way out of depths of 1000 and 1500 fathoms at the rate of about a mile per hour. Messrs. Newall were very successful in the Medi-
anean in recovering many cables by this plan; and the lecturer has seen
ible hang for three days at the bows of a ship where the depth was 800

thoms, while the ship pitched violently owing to bad weather; the cable id not break, and was relaid with success. Even in this case the rise and all of the ship did not injure the cable; but the change in the strain on the able was great, and any good elastic compensation would have been useful; he cable itself, yielding say $\frac{1}{4}$ per cent. in a mile, gives a certain elasticity. lthough this method of recovering deep-sea cables is not hopeless, the risks re great; bad weather or a weak point in the cable entail almost certain ailure. A good nipper to catch the cable, should it break inboard, as it requently does, might be of material service. Few persons will be sanguine nough to expect that a cable could be steadily picked up for 1000 consecutive hours, or say forty days, with about half its theoretical breaking-strain necessarily always upon it. We should, therefore, be grateful to the engineers in charge of the late Atlantic expedition for showing us that even in 2000 fathoms of water the attempt to hook a cable with a grapnel is far from hopeless. The chance of success by this method will now be examined. If a cable were laid absolutely taut along the bottom of the sea, when hooked by the grapnel it would rise a little way in virtue of its elasticity; if it stretched one per cent., by the time ten miles of it were off the ground the apex would be half a mile from the ground (a result few are prepared to expect); but the strain on the cable where caught would be very great, equal to the weight of about 24 miles of the cable, though the weight on the grapnel-rope would be only that of ten miles of cable. The result, therefore,

TABLE VII.

Giving length of cable lifted with a given slack, and hanging in a catenary curve, &c.

Slack in percentage.	Tension at highest point in terms of the weight of a length of cable hanging vertically from the surface to the bottom.	Length of curve in terms of versine.	Length of versine of span 100.
0	infinite	infinite	0
1	47·6	19·42	5·2
2	20·8	12·75	8·0
3	13·5	10·20	10·1
4	10·0	8·74	11·9
5	8·18	7·84	13·4
6	6·90	7·16	14·8
7	6·01	6·64	16·1
8	5·39	6·24	17·3
9	4·88	5·92	18·4
10	4·52	5·67	19·4
11	4·18	5·43	20·45
12	3·89	5·21	21·5
14	3·49	4·89	23·3
16	3·12	4·58	25·3
18	2·89	4·37	27·0
20	2·67	4·17	28·8
22	2·48	3·98	30·6
24	2·39	3·89	31·9

3. *Tests of Insulator.*—A material is said to insulate well if it offers gr resistance to the passage of a current of electricity. The word resistance i here used precisely in the sense in which it was applied to conductor conductors and insulators both resist the passage of a current—the form allowing a considerable current to be produced by a small battery, latter allowing but a feeble current to be produced by a powerful batter The object of surrounding a conductor with a good insulator is to preve any serious proportion of the current from being diverted to the sea or eart near the conductor: the insulator acts the part of the pipe, directing and containing the current; the copper acts more nearly the part of the vacan space, allowing the current to pass, and retarding it only by friction. A pipe to contain water can be made so that it shall not leak; but no material known, except dry air, will perfectly contain electricity: some leakage, indicated by a current, always occurs; and the simplest test of the soundness of the insulator is to connect one end of the conductor A (fig. 2) with one pole of a battery, Z, the other pole of which is joined to the water surrounding the insulated wire in the tank T (fig. 2). If a galvanometer, G, be placed between the battery and the conductor, and the other end of the conductor insulated, any current producing a deflection in the galvanometer must pass through the sheath from the copper to the water: such a current is often called a leakage. With a battery of known strength, and a galvanometer with which the observer is already well acquainted, the greater or less deflection of the galvanometer-needle will often be sufficient to show whether this leakage is so excessive as to indicate a flaw in the insulator connecting the water and the copper: this was the earliest insulation test; but it is clearly far from giving a measurement of the accurate kind which has been described for conductors. No two galvanometers are alike, nor is any one instrument constant in its indications; moreover an instrument of suitable delicacy for one length of insulated wire is unsuitable for another: the test is, therefore, a very rude and imperfect one; but a slight modification allows us to use it for the purpose of expressing with some accuracy the resistance of the insulato in the same units as those used for the conductor. Immediately after observing the deflection with the connexions in fig. 2, remove the insulated wir A B, and join the galvanometer and battery, as in fig. 3, inserting a set o resistance-coils at R, and joining *a b* by a short coil S, with a resistance bearin a certain definite ratio to that of the galvanometer—for instance, with $\frac{1}{999}$ par of that resistance. The current from the battery will, at *a* and *b*, divide itsel between the two branches S and G, in the ratio of 999 to 1: now adjust the resistance-coils R until the same deflection be obtained as before; then, if we call *x* the whole resistance of the circuit when connected as in fig. 3, the resistance of the circuit in fig. 2, which is sensibly equal to that of the insulating sheath, will be 1000 *x*, since the current in the first case must have been 1000 times less than in the second case, when only $\frac{1}{1000}$ part of the current flowed through the galvanometer. It will be obvious that we mig

Fig. 2.

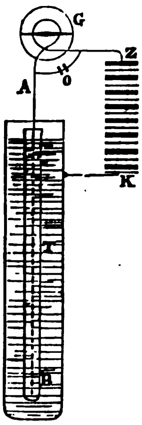
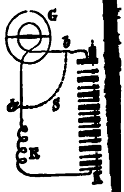


Fig. 3.



rst connexion a battery [illegible]
in the second case: [illegible]

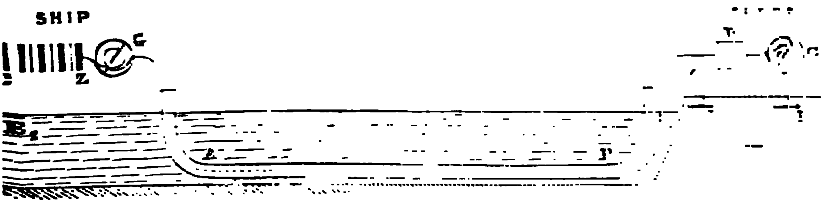
In many cases [illegible]
of the circuit. This [illegible]
and K Z be a large single [illegible]
resistance x when the [illegible]
between a and b is made up of two [illegible]
e: call S the one resistance, G [illegible]

$\frac{1}{\frac{1}{G}+\frac{1}{S}}$. To obtain the total resistance of [illegible]
battery and the resistance R. [illegible]
R need not be adjusted [illegible]
onnexion in fig. 2. If [illegible]
sistance R, the resistance [illegible]
it is unnecessary to repeat the test [illegible]
s made: we may often [illegible]
o the instrument it will remain [illegible]
g found the resistance which [illegible]
ice corresponding to other [illegible]
t is assumed, of course, that [illegible]
are proportional to the magnitude of the [illegible]
ting galvanometers. In making the test [illegible]
event the first shock of the current from [illegible]
; for this purpose a connexion of very small [illegible]
t o. This connexion must be broken [illegible]
en applied. The reason why this [illegible]
in the next Lecture. An astatic reflecting galvanometer [illegible]
magnets, of the form designed by Professor [illegible]
vill be found well adapted for this test [illegible]
ken to make the coil S (frequently [illegible]
h form as not easily to be heated [illegible]
e same temperature as the galvanometer [illegible]
remain in circuit as short a time as possible [illegible]
in the water for such a time as may [illegible]
e throughout, to practise extreme cleanliness [illegible]
nds of the wires tested to avoid loss by surface [illegible]
ther precautions have been taken [illegible]
l; but they do not approach in accuracy [illegible]
ductors: for instance, the accuracy cannot be greater [illegible]
a deflection can be observed, or, say, 1 part in [illegible]
resistance across the insulator can be measured [illegible]
ce, by using the insulator as one of the four [illegible]

It will be seen that as the length of an insulated wire [illegible]
ice to conduction across the insulator decreases; for [illegible]
arger and larger area of material to conduct [illegible]
ross the insulator from the copper to the water [illegible]
sulating sheath of 1000 miles of Malta-Alexandria [illegible]
[illegible] (or resistance) to a sheet of gutta-percha one [illegible]
in thickness separating a copper plate from
at 24° C. of this insulating sheet of [illegible]
would be about 115,000 B. A. units,

exclusively used for tests at sea, which may so far be considered quite affected by the direction of the ship or its motion. Two disturbing agen are found in the currents induced in the coils of cable as the ship rolls the so-called earth-currents, depending on the different electric pote or tension of the earth which may occur between the earth plate on sh and the connexion with the sea at the ship. These disturbances are readi overcome by the use of sufficiently strong batteries, so that no details explanation of their action need be given here. It may be granted that board ship all tests can be accurately made, and it only remains to consid what system shall be followed to ensure immediate detection of a rupture the copper conductor or an injury to the insulator. Hitherto it has been common practice to arrange a succession of tests recurring in a consta order at definite intervals of time. During the first twenty minutes of eac hour an insulation test may be used; and the simple test (fig. 2) of watching that the spot of light in the galvanometer does not quit its proper place on the scale, as it certainly will do the instant any flaw in the insulator allow a connexion between the copper and the water, is probably the best as we as the simplest. During the next twenty minutes the resistance of th copper may be measured, showing that it is unbroken, and indicating the temperature of the bottom. During the last twenty minutes speaking instruments may be connected with the cable, and intelligence given and received; then *da capo*. But this system has great defects. We may wish to send or receive intelligence when it is impossible to do so; the clerk, or clock, on shore may not keep time with the ship, and cause needless alarm or confusion; special emergencies may require special tests, and then the routine plan either prevents these or causes confusion; but worse, much worse than all this, a fatal injury to the insulation may altogether escape detection during the periods allotted for continuity tests and speaking; it may pass over into the sea, and, when finally discovered, may be some miles from the ship. It would be better to maintain constantly a simple insulation test, and let the shore end remain insulated and unwatched. No fault could then occur in the insulator without being instantly detected; and even a break in the copper, inside the insulator, would be shown by a sudden fall in the leakage, owing to the shorter length of cable which would then be under the action of the test. A simultaneous injury to insulator and conductor would be still more obviously indicated; but such a plan as this would result in voluntarily throwing away the assistance to be derived from intelligent observations on shore, which, it will be seen in the next Lecture, may give important assistance in determining the position of a fault when it does occur. To meet this dilemma plans have lately been devised by which an insulation test on the ship and a simultaneous insulation test on shore can be nearly constantly maintained; speaking can be practised at any moment by ship or shore, and even during the transmission of messages the insulation test need not be wholly suspended. The first of these plans, in order of publication if not of conception, is due to Mr. Willoughby Smith. The connexions required are shown in fig. 4. C Z is the ship battery; E_2 the ship earth plate, or sea connexion; G the marine galvanometer; A B the cable, connected at the shore end with a great resistance R, equal to, say, the insulation resistance of four or five knots of cable. G_1 is a very delicate galvanometer on shore, placed between the resistance R and the earth plate. When these connexions are made, a slight deflection on the ship galvanometer, G, will indicate the normal leakage of current through the gutta-percha. Almost the full tension of the battery will act on R, and cause a feeble curt to pass through this resistance, causing [illegible] is feeble current will of course [illegible] be equal to the gutta-percha [illegible] g, the leakage through I will [illegible] l this may be neglected [illegible]

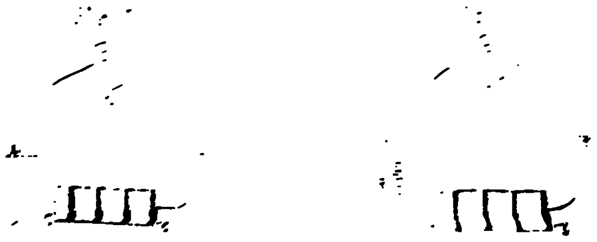
Fig. 4



stantly increase the deflection on G, will lower the tension of the battery [illegible] ting on R, and so diminish the deflection on G, [illegible] will both [illegible] advised of the misfortune. A break of continuity in the copper of [illegible] ithout loss of insulation, will diminish the deflection on G and [illegible] the deflection at G_1 after a little while [illegible] there will be a great increase in the deflection of G and [illegible] ll deflection on G_1. The shore can, without [illegible] unicate with the ship by making [illegible] arth and the cable at a. This will [illegible] ut if a resistance be inserted [illegible] will be small, so that [illegible] n G, by causing a [illegible] ven during the signal [illegible] attery or by [illegible] est on board [illegible] t is to be hoped that [illegible] t gives perfect [illegible] etecting any fault [illegible] aults always [illegible] r in the manner [illegible] attaining the same [illegible]

APPENDIX [illegible]

First make the [illegible] battery to [illegible] resistance of the [illegible] let it be [illegible]



test joints. The ends of a short wire to be tested should also be
t. Ebonite, after being in use for instruments for some time, often
to be freshly polished. As an example of what can be done by
proper materials and by drying the atmosphere, so as to prevent
film from being deposited on the surface, the lecturer can, from his
rience, state that Leyden jars, in Professor Thomson's electrometers,
made to hold their charge so well that not one half per cent. will
in 24 hours. Such a cable as the Atlantic falls from charge to half
in about fifteen minutes. Some wires, covered by Hooper's material,
n charge to half charge in from seven hours to two days.

nduction Tests.—Hitherto the word charge has been used as having a
vith which all are familiar, and the indications of an electrometer,
really measures tension or difference of potential from the earth,
een received as evidence of a greater or smaller charge; it is time to
these expressions. The charge of electricity which an insulated body
ceive really means a definite quantity of electricity. This quantity,
scaping to the earth, which is assumed to be at zero tension, produces a
nt equal to the quantity divided by the time occupied in [illegible]
are said to contain equal charges when these charges will produce in
ischarge equal currents. A charge held by a body is said to [illegible]
tension or potential, meaning the quality measured by the [illegible]
above described. The total charge which a given body [illegible]
nces will receive is proportional to the potential or tension to [illegible]
ised. Thus the charge produced by contact with the pole of a battery
cells is fifty times that produced by a single cell. The [illegible]
ial produced by a frictional machine is of exactly the same nature as
roduced by the voltaic battery; it is simply greater in amount. Thus
may be charged equally by sparks from an electrophorus and [illegible]
battery; then if this charge be allowed to escape through a galvanometer
the current in each case will be equal, and produce an equal deflection
and, again, if two bodies are charged to the same potential [illegible]
t with one pole of the same battery, then if the current produced by
scharge from the two be equal the charges on both are equal and the
ity of both bodies was equal. The capacity of a body for [illegible]
e depends on many elements; it increases as the external surface of
ody increases, and it increases as the surrounding bodies in [illegible] Thus
the earth are brought near to the insulated electrified body.
ity of a Leyden jar, where the inner electrified surface is [illegible]
to the outer unelectrified surface, is much greater than that of
e of equal surface in a large room. The general laws [illegible]
ity and potential are too complex to be here explained [illegible]
cable increases directly as its length, just as the capacity of [illegible]
en jars is double that of one. The gutta percha and the [illegible]
opper that of the inner tinfoil; the water or moist [illegible]
the outer uninsulated coating. Owing to the large [illegible]
ness of the insulation, the capacity of a long cable [illegible]
arge can be shown on almost any galvanometer [illegible]
can be seen on a sensitive instrument if charged by [illegible]

Fig. 2 shows the connexions required to show [illegible]
mon key, by which the conductor of the cable [illegible]
nnexion with the battery Z C by a contact at [illegible]
attery, and immediately connected at *a* with the [illegible]
r, G, the other terminal of which is in [illegible]

The contact at p charges the cable, and that at e discharges it through th galvanometer. It will readily be seen that as the quantity which goes in the cable must be equal to that which leaves it, if the galvanometer G w placed between b and B, it would be affected to the same extent by th entrance of the charge as by its exit at A. With a well insulated cable, d flections due to the rush in or out of the charge are far greater than th due to leakage across the sheath; and it is to avoid the disturbance due t this momentary current that in making insulation tests no sensible part of th current is at first allowed to run through the galvanometer, but is conducted through a short circuit as at s, fig. 2. Lecture IV. The deflection due to the charge or discharge of a short cable is the result of a single very short im pulse; and this deflection may be used to measure the charge in two way First we may make a standard kind of cable or Leyden jar, or condenser a it is sometimes called; we may take the discharge from that, as in fig. 3,

Fig. 2.

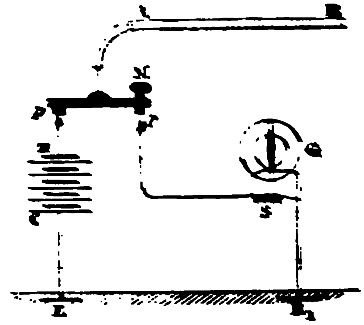
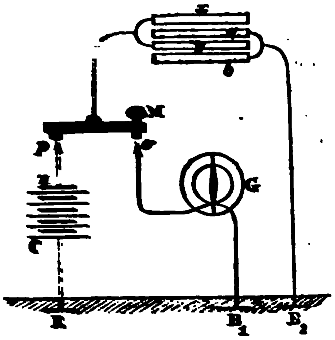


Fig. 3.



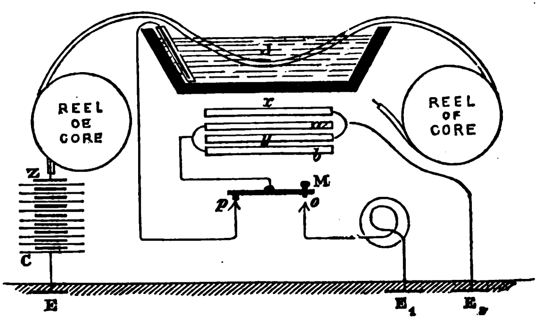
where a b represent plates in connexion with the earth, and x y insulated plates separated from them by mica, gutta-percha, paraffin, glass, or air, the other connexions being the same as in fig. 2. Next we may charge the cable from the same battery, and by trial bring the galvanometer to the same deflection by shunting part of the current through coils, which can be adjusted: if $\frac{1}{100}$ part of the current pass through G, then the capacity of the cable is one hundred times that of the condenser: the relative charges, if not differing much, may be taken as proportional to the deflections on a reflecting galvanometer, or, more strictly, to the sines of half the angles on any instrument. A galvanometer with a comparatively heavy needle is better for this purpose than a reflecting instrument with mirror and light magnets, owing to the resistance of the air. The comparison of capacities may be made in a much more accurate manner by various less well-known devices, as:—by the transfer of a charge from one condenser to another, and the measurement of the potential before and after the transfer: by the relative effect of two discharges in opposite directions through a differential galvanometer; by balancing a succession of discharges through one coil of a differential galvanometer against a permanent current adjusted with the aid of resistance-coils; and by balancing the discharges against a permanent current in an arrangement resembling a Wheatstone balance.

arrangements have, it is believed, not yet been used as practical tests; will be useful to give here a formula by which we may compare the of any two or more observers, who have not got galvanometers which have compared, or condensers of known relative capacities. Let he capacity of a conductor measured in the units required for equa- 3); let t = half the time of a complete oscillation of the needle of the iometer under the influence of terrestrial magnetism alone, i = the to which the needle is thrown by the momentary current, R_1 = the ınce in B. A. units of the circuit through which the battery used to e the cable would produce the unit deflection on the galvanometer, then

$$S = 2\frac{t \sin \frac{1}{2} i}{\pi R_1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

ccuracy with which this measurement can be made is not very great, ; to the difficulty of measuring t on most instruments. The charge is o be due to induction, and these tests are called induction tests; it now ns to show their practical application. The discharge may be used to ıre insulation, thus: charge the cable by contact at p (fig. 2), and then contact at p without making contact at o; the charge which is, as it bottled up inside the cable, leaks gradually through the gutta-percha. , say, one minute, make contact at o, and observe the difference between eflection thus obtained and that obtained when the cable is discharged diately after being charged. The difference measures the loss in one te. The galvanometer can in this way, by successive trials, be used to :ain the rate at which the charge is lost for all the tests described as measured with the electrometer, though less conveniently. A ır test is applied by Messrs. Bright and Clark to the testing of joints. nt (fig. 4) is placed in an insulated trough of water connected with a nser, the battery is applied to one end of the cable, and any slight ge which may occur at the joint gradually accumulates in the condenser. a minute or more the condenser is discharged through a galvanometer, ı may then show the result of a minute's accumulation even when the ınent current passing at any moment would not have been sensible. hese are only the indirect consequences of the induction test. Its main

Fig. 4.



; is to compare the capacities of various cables and the inductive rties of various materials; and the reason why these points are im- nt is, that the number of words which can be transmitted per minute gh long submarine cables is, *cæteris paribus*, inversely proportional to capacity; so that a long cable A, each knot of which will, from a given ry, receive only half the charge received by cable B (equal to A in other *ıts), will transmit double* the number of words per minute. The cause

R.

of this cannot here be explained, but the fact is experimentally and theo tically proved. By theory, the charge on equal lengths of two wires, cover with the same insulator, should be inversely proportional to log $\frac{D}{d}$, where and d, as before, indicate the diameter of the insulator and conductor: b the capacity also varies with the insulator used; thus the charge on a kn of the Persian-Gulf cable, insulated with gutta-percha, was 35 per cen greater than a knot of similar dimensions insulated by Hooper's material and was somewhat more than four times greater than the charge would hav been had it been possible to find an insulator with the properties of ai instead of gutta-percha. The property of a material in virtue of which i affects the charge is called its inductive capacity, and the ratio of the charg induced when the solid material is used to that which would be induced i air were the insulator is called the specific inductive capacity of the material It will be seen that equation (9) gives the means of expressing the capacity o a knot of cable in certain units. Table XIII. gives the calculated capacit of some cables and materials in these units, with the specific inductiv capacity of gutta-percha, india-rubber, and Hooper's material. These numbers are very much less well ascertained than the resistance measurements given in previous tables. Nevertheless improvement in this quality is of very much greater importance than improvement in insulation resistance. Neither temperature nor pressure seems to affect the charge or capacity o cables very materially.

4. *Tests to detect Faults.*—Faults in cables may be classed as follows:—1. A fracture or interruption in the copper conductor, which, nevertheless, remains insulated inside the gutta-percha covering. 2. A fracture of the copper conductor and gutta-percha, in which a considerable length of copper wire remains exposed to the water. 3. A fault intermediate between the first two, with copper and gutta-percha both broken, but little copper exposed. 4. A connexion between the iron covering and the copper by a nail or wire driven in. 5. A hole or imperfection in the gutta-percha sheath, establishing a connexion of considerable resistance between the conductor and the sea. The first of these faults is of course followed by a total cessation of all electrical communication between the two ends of the cable. Its position may be detected in two ways. The charge which the cable will contain may be measured as above described; and if the charge per knot is known, the charge observed will directly give the distance of the break; and the accuracy with which the position of the fault can be determined is limited only by the accuracy with which the relative charges can be compared: the cable is an insulated Leyden jar, the capacity of which is simply proportional to the length of the conductor from the shore to the fault; so that if the discharge from a knot of the cable, with a given battery and reflecting galvanometer, is represented by a deflection of ten divisions, and the discharge from a cable containing a broken copper conductor is 100 divisions, we may feel certain that the fault is about ten miles from shore. By the more accurate modes of comparing discharges, the distance of a fault of this kind, even on a long cable, might be accurately found. The method by the throw or deflection of a needle is not applicable to a very long cable, because of the time occupied by the discharge; the theory of the formula given above supposes that the needle moves under a sudden impulse, very short compared with the time of oscillation of the needle. A second plan of determining the position of this kind of fault is t ure the resistance of the insulating sheath. Thus, if we know by th

TABLE XIII.—INDUCTION TESTS.

Name of Cable.	Material.	S=Electro-magnetic capacity per knot, multiplied by 10^{12}.	s=Electrostatical capacity per knot, in absolute measure (French).	Specific inductive capacity $I=3{\cdot}281 \times \frac{2\,s}{6087} \log_\epsilon \frac{D}{d}$ (English).	Source of Information.
Malta-Alexandria	Gutta-percha	0·0399	3583	4·18	Calculated from value of I given by F. Jenkin. Report on Electrical Instruments, Class XIII., International Exhibition, 1862.
Atlantic cable..........	Gutta-percha	0·0345	3340	4·3	Condenser adjusted by Mr. Willoughby Smith. Experiments by F. Jenkin and Chas. Hockin.
Persian-Gulf cable	Gutta-percha	0·0323	3120	4·2	Condenser adjusted by J. C. Laws. Experiments as above.
Hooper's cable, Persian-Gulf pattern	Partly vulcanized India-rubber	0·0239	2310	3·11	Compared by Prof. W. Thomson, and independently by Messrs. Bright and Clark, with Persian-Gulf gutta-percha cable.
	Masticated India-rubber	....	....	2·82	Jurors' Report, International Exhibition, as above.

discharge-test that the cable is insulated where broken, and find t insulation resistance to be 1000 units, whereas the insulation resistance one knot is 1,000,000 units, we may conclude that the fault is 1000 mil off, as it will require one thousand miles of sound core to give so small resistance as 1000 units. Faults of this kind are very rare where strands copper properly jointed are used. The second kind of fault enumerated al wholly stops communication between the two ends of the cable, and alm invariably occurs when a cable is broken with violence. The copper a gutta-percha are then both stretched, and the gutta-percha springs bac when the copper breaks, and leaves the latter exposed: but sometimes th copper breaks some little way from where the gutta-percha yields and insid it; then the third kind of fault occurs, intermediate between the two forme When some inches of copper are exposed, a connexion of small resistance i formed with the sea. In this case the resistance of the copper conducto measured from the shore, measures the distance of the fault; we know th resistance per knot, and if we observe 500 times this resistance, the fault i 500 miles off, the resistance of the earth itself being *nil*. A small correctio ought of course to be made for conduction through the insulator when soun but in good cables this may be neglected. It is by this test that the operato at Valencia are able to tell that they have still the full length of the cab between them and the spot where the cable was first broken. There is litt difficulty in determining whether a fault of this nature has occurred; for th comparatively small resistance of the cable shows that it is connected wi the sea where it ought not to be, and the constancy of that resistance show the connexion to be complete. This brings us to the third class of faul where the connexion between the sea and the copper exists, but is imperfect or due to only a small area of exposed copper. The fault itself then possess considerable resistance, sometimes more than that of all the copper conducto of the cable; and, what is worse, this resistance is inconstant, varying rapidly and capriciously between extremely wide limits. The test for resistance in that case simply tells us that the fault cannot be beyond the distance corresponding to the smallest resistance observed. The fourth kind of fault corresponds almost exactly in behaviour to the second, but the connexion with the sea is still more perfect; the resistance will vary still less, and there will be a total absence of the feeble currents which result from the copper and iron of a cable when broken and separated by salt water. Earth currents, due to a difference of potential between the shore and sea at the fault, may of course, in both cases, be observed. The fifth kind of fault is easily detected: there is a considerable fall in the insulation resistance, and a slight or moderate fall in the apparent resistance of the copper conductor between the two stations; but messages can still be transmitted, as a portion only of the whole current, inversely proportional to the resistance of the fault, escapes into the sea. If one station insulates the cable and the other measures the resistance, the fault behaves like a fault of the third class, and this test will not detect its position. If, however, the resistance of the fault remain constant, and the two measurements of resistance, R and r, be made from station A, when station B respectively insulates the end of the cable and connects it with the earth, we obtain two equations concerning the resistances, in which there is only one unknown quantity, viz. the resistance of the fault. When this is eliminated, the following equation is obtained:—

$$D = r - \sqrt{(R - r)(L - r)}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

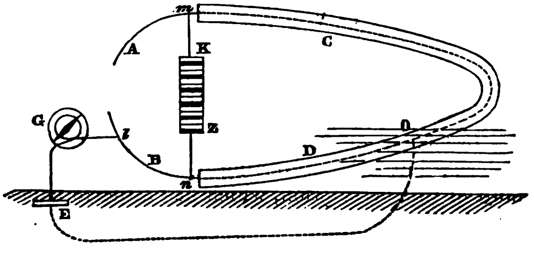
$D =$ the resistance of the conductor between the fault and the observer,

= the resistance of the whole conductor between the stations. On ›ng cables a correction for the effect of the uniform leakage through ›ulator would be necessary; but this correction fades into insignificance ›parison with the error introduced by the supposition that the resistance fault will remain constant during the two tests. Successive tests from 'o stations, the distant end being insulated in each case, will also give ›uations, by which, on the same supposition that the resistance of the 'emains constant, its position can be determined. Then calling R and › resistance in the two cases, we have—

$$D = \frac{L + (R - R_1)}{2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

D is the resistance of the conductor between the station which 'ed the resistance R and the fault. This test labours under the same as the previous one. When a return insulated wire can be substituted e earth, so that the observer has both ends of a complete metallic circuit him, the position of a fault such as is described, even of varying ›nce, can be accurately determined by more than one method. Mr. ŗ uses a diffential galvanometer, a well-known instrument, to ascertain an equal current runs into both ends of the metallic circuit and out at ult. This will only be the case when the resistance between the galvaer and the fault is the same by both roads; this condition is easily ›d by adding resistance-coils between one coil of the galvanometer and fective wire. The resistance which must thus be added to bring the ıometer to zero is obviously equal to twice the resistance of the metallic ctor between the fault and the distant station. Prof. Wheatstone's ›e may be so arranged as to give another method, by making the con- ıs as in fig. 5, where the fault, supposed to be at *o*, forms, as it were, f the galvanometer wire. In this case, as in the preceding, a variation resistance of the fault does not affect the result; it will cause a greater › deflection in the galvanometer until the desired balance is effected; will not alter the relative resistances of the several parts of the main › required to reduce the deflection to zero. The test in fig. 5 is made justing the relative resistances of A and B until no deflection is ›ed; then the fault will be at a point such that $\frac{A}{B} = \frac{C}{D}$, where C and resent the resistance of the conductor separating *m* from the fault and ı the fault. When the total resistance of the conductor is known, this ive the position of the fault very accurately. Mr. John Murray, of ›w, is said by Professor Thomson to have first applied this test on board *'iagara ' during the first* Atlantic expedition. Is was reinvented by the

Fig. 5.



precisely in proportion to the decrease of resistance between any
point and earth; so that if the wires AB, CD were straightened ou
fig. 8, and the resistance represented by their length, the fall of tensi
each wire would be exactly represented by the height of the dotted s
line shown above each conductor, the maximum height being supp
correspond to the full tension of the battery. The current in the tw
would of course be very different, but halfway along each the tension
be equal to half the maximum; at two thirds the distance, it would i
wire be two thirds of the maximum, and so on. Now if two points
conductors, at equal potentials or tensions, are joined by a wire, no
will pass along that wire, for a current is always due to a di
of tension acting like a head of water: the case is analogous to th
pipe joining two reservoirs; if the water in each be at the same l
current will flow through the pipe, no matter how deep the reservo
be; so that if the galvanometer wires are applied to two points so cho
$\frac{A}{B}=\frac{C}{D}$, the tensions at those points being equal, no current w
through the galvanometer. But if the wires are applied as at *y*
current will pass through in the direction of the arrow; and if the w
applied as at *z* and *w*, a current in an opposite direction will pass; so
trial we may always ascertain the exact points at which the c
$\frac{A}{B}=\frac{C}{D}$ is fulfilled. The dotted line round A B C D in fig. 7 corres
the dotted line in fig. 8, and represents the gradual fall of tensions.
the galvanometer wires are applied as at *y* and *x* or *w* and *z*, thi
line should be slightly modified; but the modification will not affect t
of the above reasoning.

Full size view

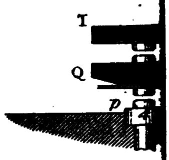


Fig. 2. Fl

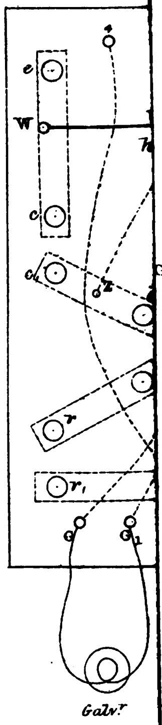


Fig 7. Diagram of connexions when commutator is in position drawn (Fig. 1) d connected with d_1 & f with f_1.

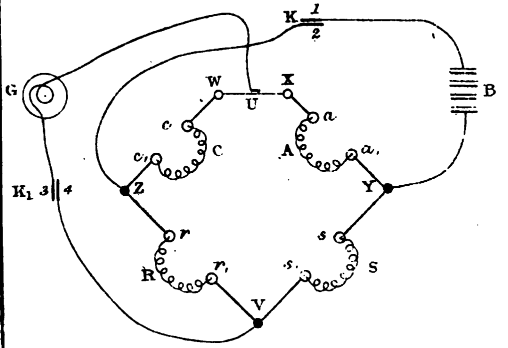


Fig. 8. Diagram of connexions with commutator D placed across board, d connected with f & d_1 with f_1

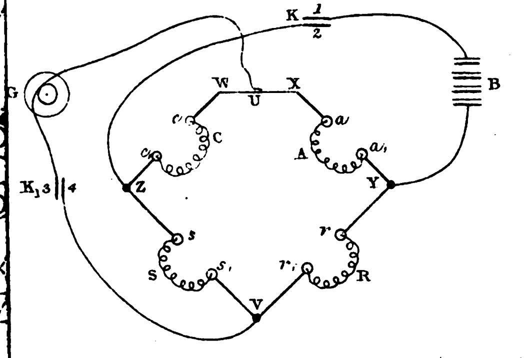
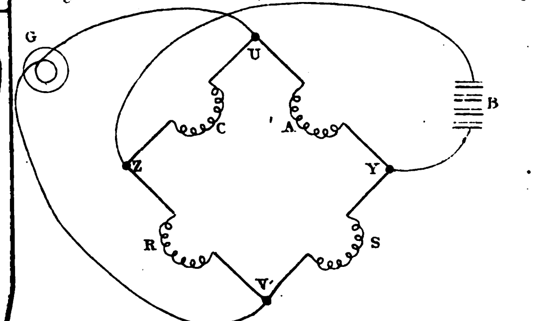


Fig. 9. Common Bridge



LIBRARY
LENOX AND
FOUNDATIONS
L

port British Assoc. 1863.

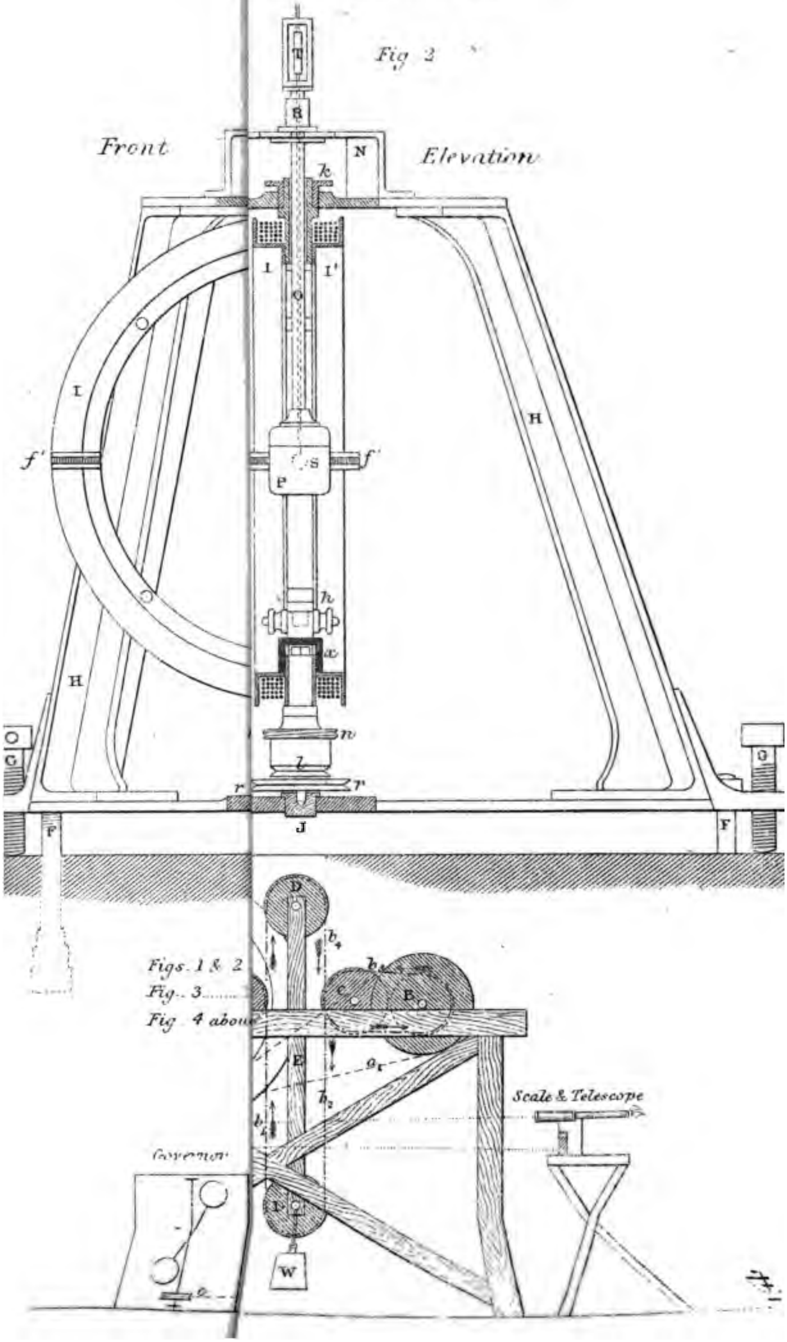
ON APPARATUS,

on of Electrical Resistance in

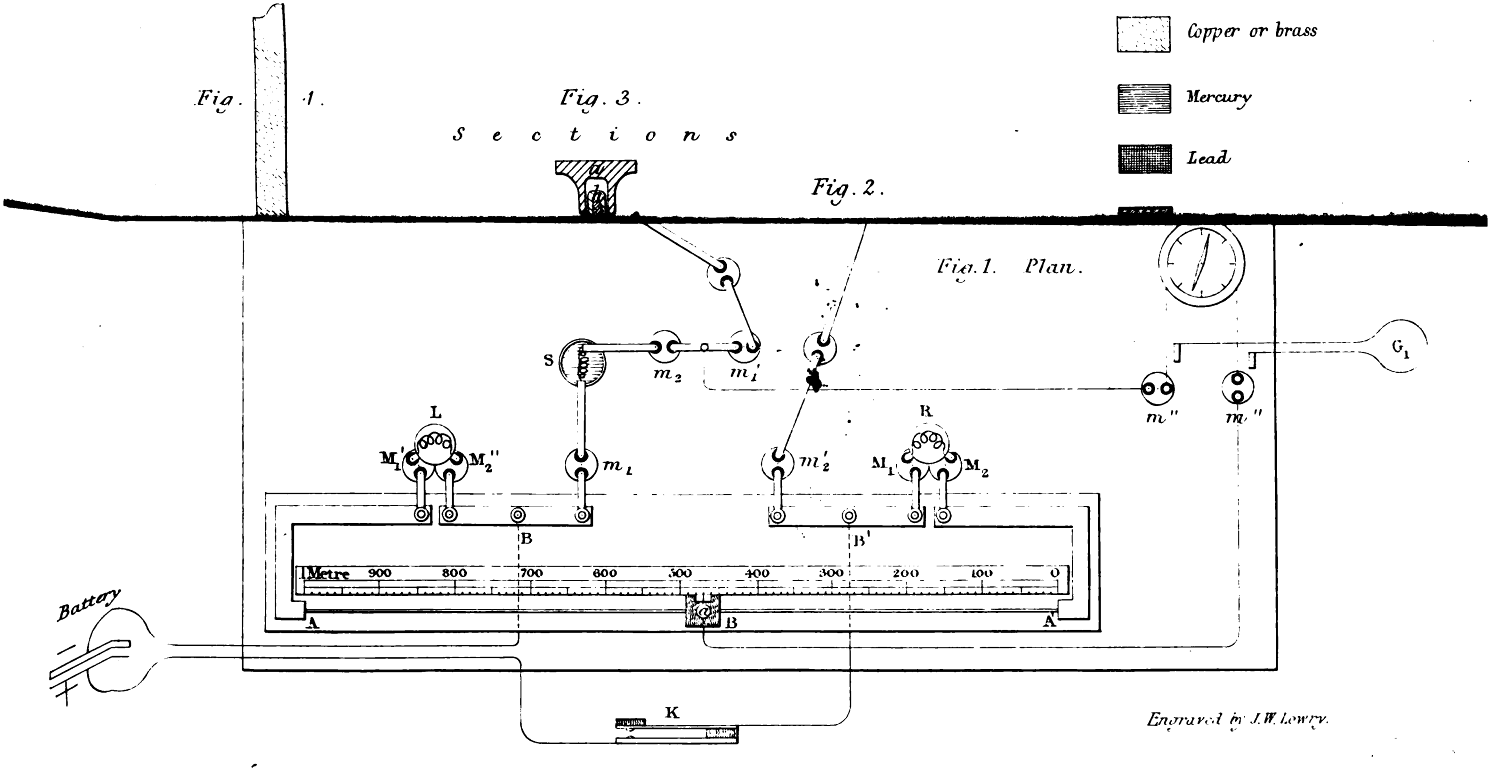
CTRO-MAGNETIC UNITS.

Fig. 2

Front Elevation



X AND
DATIONS
L

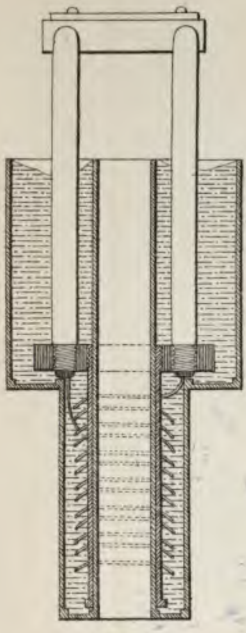


Engraved by J.W. Lowry.

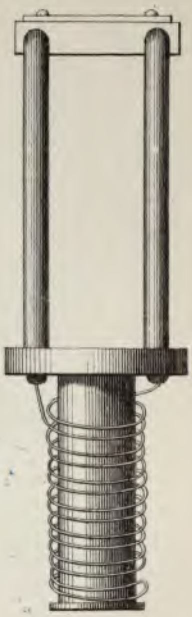
THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS
R L

Standard unit of Electrical Resistance.



SECTION.



ELEVATION.

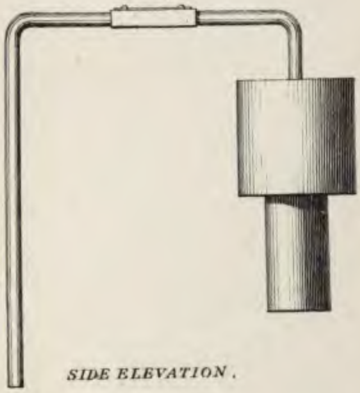
½ full size.

▨ *Metal.*

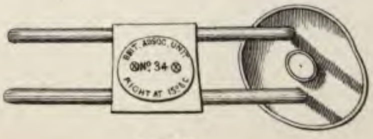
▨ *Ebonite.*

▨ *Parafine.*

▨ *Solder.*



SIDE ELEVATION.



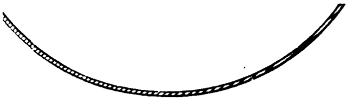
PLAN.

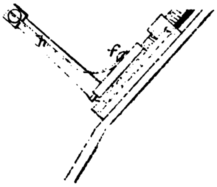
THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS

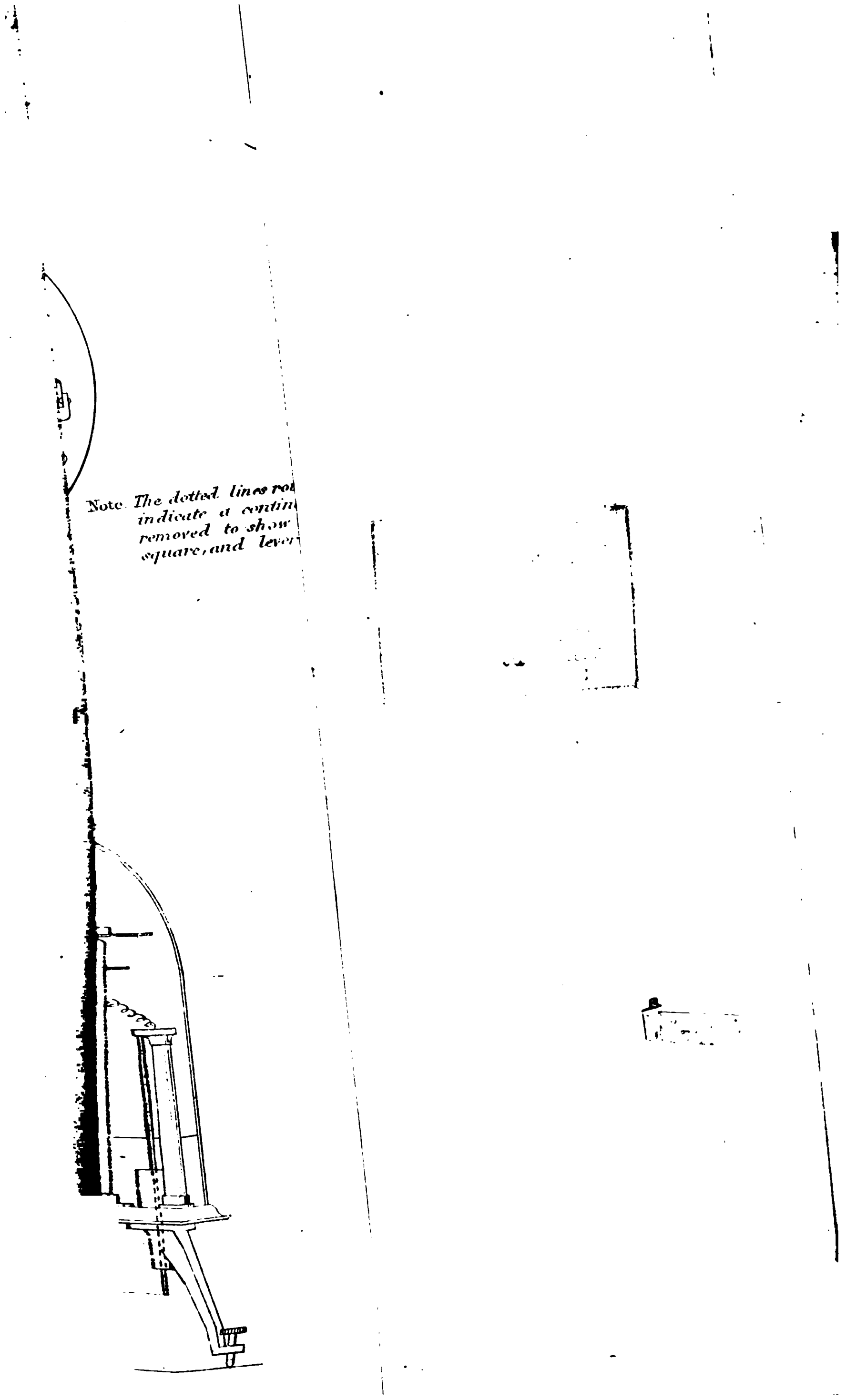
37

AST
TILDEN FOU
B



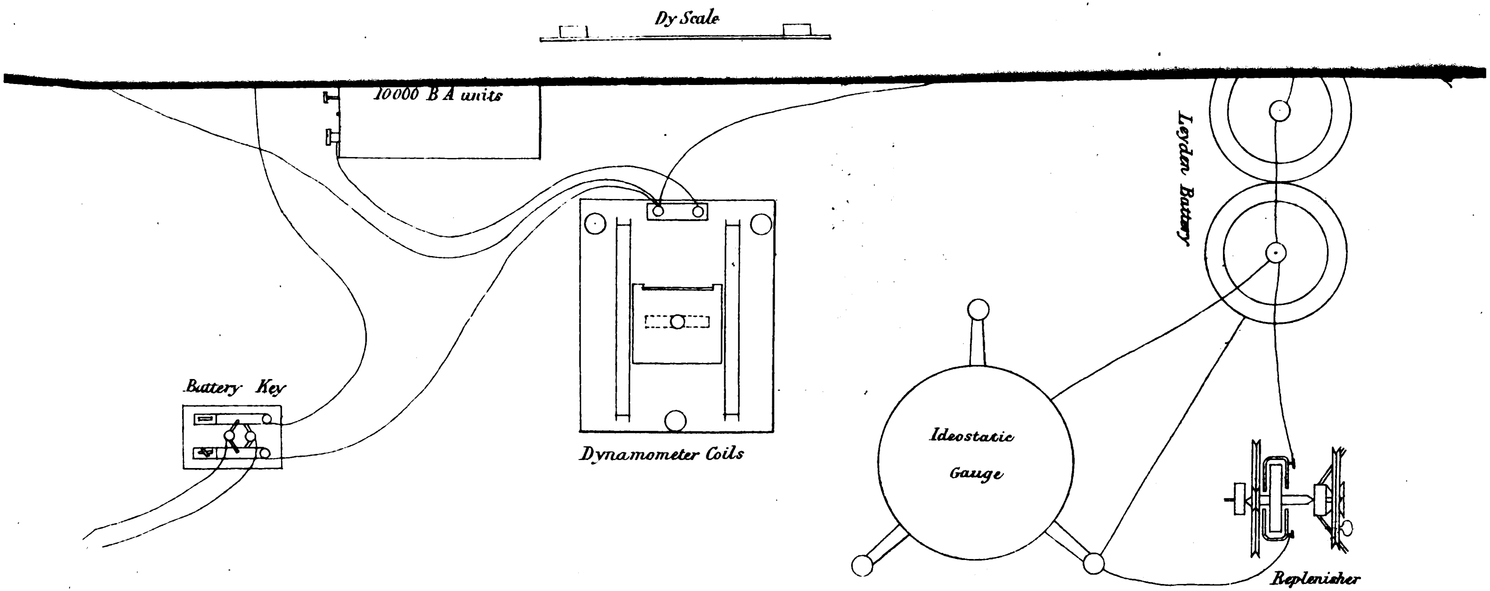


YORK
[illegible] LIBRARY
[illegible] LENOX AND
[illegible]



Note. The dotted lines ro
indicate a contin
removed to show
square, and leve

NEW YORK
LIBRARY
AND


Dy Scale
10000 B A units
Leyden Battery
Battery Key
Dynamometer Coils
Ideostatic
Gauge
Replenisher

THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS
B L

1888.

BOOKS RELATING
TO
APPLIED SCIENCE,

PUBLISHED BY

E. & F. N. SPON,

LONDON: 125, STRAND.

NEW YORK: 12, CORTLANDT STREET.

A Pocket-Book for Chemists, Chemical Manufacturers, Metallurgists, Dyers, Distillers, Brewers, Sugar Refiners, Photographers, Students, etc., etc. By THOMAS BAYLEY, Assoc. R.C. Sc. Ireland, Analytical and Consulting Chemist and Assayer. Fourth edition, with additions, 437 pp., royal 32mo, roan, gilt edges, 5*s.*

SYNOPSIS OF CONTENTS:

Atomic Weights and Factors—Useful Data—Chemical Calculations—Rules for Indirect Analysis—Weights and Measures—Thermometers and Barometers—Chemical Physics—Boiling Points, etc.—Solubility of Substances—Methods of Obtaining Specific Gravity—Conversion of Hydrometers—Strength of Solutions by Specific Gravity—Analysis—Gas Analysis—Water Analysis—Qualitative Analysis and Reactions—Volumetric Analysis—Manipulation—Mineralogy—Assaying—Alcohol—Beer—Sugar—Miscellaneous Technological matter relating to Potash, Soda, Sulphuric Acid, Chlorine, Tar Products, Petroleum, Milk, Tallow, Photography, Prices, Wages, Appendix, etc., etc.

The Mechanician: A Treatise on the Construction and Manipulation of Tools, for the use and instruction of Young Engineers and Scientific Amateurs, comprising the Arts of Blacksmithing and Forging; the Construction and Manufacture of Hand Tools, and the various Methods of Using and Grinding them; the Construction of Machine Tools, and how to work them; Machine Fitting and Erection; description of Hand and Machine Processes; Turning and Screw Cutting; principles of Constructing and details of Making and Erecting Steam Engines, and the various details of setting out work, etc., etc. By CAMERON KNIGHT, Engineer. *Containing* 1147 *illustrations,* and 397 pages of letter-press, Fourth edition, 4to, cloth, 18*s.*

Just Published, in Demy 8vo, cloth, containing 975 pages and 250 Illustrations, price 7s. 6d.

SPONS' HOUSEHOLD MANUAL:

A Treasury of Domestic Receipts and Guide for Home Management.

PRINCIPAL CONTENTS.

Hints for selecting a good House, pointing out the essential requirements for a good house as to the Site, Soil, Trees, Aspect, Construction, and General Arrangement; with instructions for Reducing Echoes, Waterproofing Damp Walls, Curing Damp Cellars.

Sanitation.—What should constitute a good Sanitary Arrangement; Examples (with illustrations) of Well- and Ill-drained Houses; How to Test Drains; Ventilating Pipes, etc.

Water Supply.—Care of Cisterns; Sources of Supply; Pipes; Pumps; Purification and Filtration of Water.

Ventilation and Warming.—Methods of Ventilating without causing cold draughts, by various means; Principles of Warming; Health Questions; Combustion; Open Grates; Open Stoves; Fuel Economisers; Varieties of Grates; Close-Fire Stoves; Hot-air Furnaces; Gas Heating; Oil Stoves; Steam Heating; Chemical Heaters; Management of Flues; and Cure of Smoky Chimneys.

Lighting.—The best methods of Lighting; Candles, Oil Lamps, Gas, Incandescent Gas, Electric Light; How to test Gas Pipes; Management of Gas.

Furniture and Decoration.—Hints on the Selection of Furniture; on the most approved methods of Modern Decoration; on the best methods of arranging Bells and Calls; How to Construct an Electric Bell.

Thieves and Fire.—Precautions against Thieves and Fire; Methods of Detection; Domestic Fire Escapes; Fireproofing Clothes, etc.

The Larder.—Keeping Food fresh for a limited time; Storing Food without change, such as Fruits, Vegetables, Eggs, Honey, etc.

Curing Foods for lengthened Preservation, as Smoking, Salting, Canning, Potting, Pickling, Bottling Fruits, etc.; Jams, Jellies, Marmalade, etc.

The Dairy.—The Building and Fitting of Dairies in the most approved modern style; Butter-making; Cheesemaking and Curing.

The Cellar.—Building and Fitting; Cleaning Casks and Bottles; Corks and Corking; Aërated Drinks; Syrups for Drinks; Beers; Bitters; Cordials and Liqueurs; Wines; Miscellaneous Drinks.

The Pantry.—Bread-making; Ovens and Pyrometers; Yeast; German Yeast; Biscuits; Cakes; Fancy Breads; Buns.

The Kitchen.—On Fitting Kitchens; a description of the best Cooking Ranges, close and open; the Management and Care of Hot Plates, Baking Ovens, Dampers, Flues, and Chimneys; Cooking by Gas; Cooking by Oil; the Arts of Roasting, Grilling, Boiling, Stewing, Braising, Frying.

Receipts for Dishes—Soups, Fish, Meat, Game, Poultry, Vegetables, Salads, Puddings, Pastry, Confectionery, Ices, etc., etc.; Foreign Dishes.

The Housewife's Room.—Testing Air, Water, and Foods; Cleaning and Renovating; Destroying Vermin.

Housekeeping, Marketing.

The Dining-Room.—Dietetics; Laying and Waiting at Table; Carving; Dinners, Breakfasts, Luncheons, Teas, Suppers, etc.

The Drawing-Room.—Etiquette; Dancing; Amateur Theatricals; Tricks and Illusions; Games (indoor).

The Bedroom and Dressing-Room; Sleep; the Toilet; Dress; Buying Clothes; Outfits; Fancy Dress.

The Nursery.—The Room; Clothing; Washing; Exercise; Sleep; Feeding; Teething; Illness; Home Training.

The Sick-Room.—The Room; the Nurse; the Bed; Sick Room Accessories; Feeding Patients; Invalid Dishes and Drinks; Administering Physic; Domestic Remedies; Accidents and Emergencies; Bandaging; Burns; Carrying Injured Persons; Wounds; Drowning; Fits; Frost-bites; Poisons and Antidotes; Sunstroke; Common Complaints; Disinfection, etc.

The Bath-Room.—Bathing in General; Management of Hot-Water System.

The Laundry.—Small Domestic Washing Machines, and methods of getting up linen; Fitting up and Working a Steam Laundry.

The School-Room.—The Room and its Fittings; Teaching, etc.

The Playground.—Air and Exercise; Training; Outdoor Games and Sports.

The Workroom.—Darning, Patching, and Mending Garments.

The Library.—Care of Books.

The Garden.—Calendar of Operations for Lawn, Flower Garden, and Kitchen Garden.

The Farmyard.—Management of the Horse, Cow, Pig, Poultry, Bees, etc., etc.

Small Motors.—A description of the various small Engines useful for domestic purposes, from 1 man to 1 horse power, worked by various methods, such as Electric Engines, Gas Engines, Petroleum Engines, Steam Engines, Condensing Engines, Water Power, Wind Power, and the various methods of working and managing them.

Household Law.—The Law relating to Landlords and Tenants, Lodgers, Servants, Parochial Authorities, Juries, Insurance, Nuisance, etc.

On Designing Belt Gearing. By E. J. COWLING WELCH, Mem. Inst. Mech. Engineers, Author of 'Designing Valve Gearing.' Fcap. 8vo, sewed, 6*d.*

A Handbook of Formulæ, Tables, and Memoranda, for Architectural Surveyors and others engaged in Building. By J. T. HURST, C.E. Fourteenth edition, royal 32mo, roan, 5*s.*

"It is no disparagement to the many excellent publications we refer to, to say that in our opinion this little pocket-book of Hurst's is the very best of them all, without any exception. It would be useless to attempt a recapitulation of the contents, for it appears to contain almost *everything* that anyone connected with building could require, and, best of all, made up in a compact form for carrying in the pocket, measuring only 5 in. by 3 in., and about ¾ in. thick, in a limp cover. We congratulate the author on the success of his laborious and practically compiled little book, which has received unqualified and deserved praise from every professional person to whom we have shown it."—*The Dublin Builder.*

Tabulated Weights of Angle, Tee, Bulb, Round, Square, and Flat Iron and Steel, and other information for the use of Naval Architects and Shipbuilders. By C. H. JORDAN, M.I.N.A. Fourth edition, 32mo, cloth, 2*s.* 6*d.*

A Complete Set of Contract Documents for a Country Lodge, comprising Drawings, Specifications, Dimensions (for quantities), Abstracts, Bill of Quantities, Form of Tender and Contract, with Notes by J. LEANING, printed in facsimile of the original documents, on single sheets fcap., in paper case, 10*s.*

A Practical Treatise on Heat, as applied to the Useful Arts; for the Use of Engineers, Architects, &c. By THOMAS BOX. *With* 14 *plates.* Third edition, crown 8vo, cloth, 12*s.* 6*d.*

A Descriptive Treatise on Mathematical Drawing Instruments: their construction, uses, qualities, selection, preservation, and suggestions for improvements, with hints upon Drawing and Colouring. By W. F. STANLEY, M.R.I. Fifth edition, *with numerous illustrations,* crown 8vo, cloth, 5*s.*

Quantity Surveying. By J. LEANING. With 42 illustrations. Second edition, revised, crown 8vo, cloth, 9*s.*

CONTENTS:

A complete Explanation of the London Practice.
General Instructions.
Order of Taking Off.
Modes of Measurement of the various Trades.
Use and Waste.
Ventilation and Warming.
Credits, with various Examples of Treatment.
Abbreviations.
Squaring the Dimensions.
Abstracting, with Examples in illustration of each Trade.
Billing.
Examples of Preambles to each Trade.
Form for a Bill of Quantities.
Do. Bill of Credits.
Do. Bill for Alternative Estimate.
Restorations and Repairs, and Form of Bill.
Variations before Acceptance of Tender.
Errors in a Builder's Estimate.
Schedule of Prices.
Form of Schedule of Prices.
Analysis of Schedule of Prices.
Adjustment of Accounts.
Form of a Bill of Variations.
Remarks on Specifications.
Prices and Valuation of Work, with Examples and Remarks upon each Trade.
The Law as it affects Quantity Surveyors, with Law Reports.
Taking Off after the Old Method.
Northern Practice.
The General Statement of the Methods recommended by the Manchester Society of Architects for taking Quantities.
Examples of Collections.
Examples of "Taking Off" in each Trade.
Remarks on the Past and Present Methods of Estimating.

Spons' Architects' and Builders' Price Book, with useful Memoranda. Edited by W. YOUNG, Architect. Crown 8vo, cloth, red edges, 3*s.* 6*d.* *Published annually.* Sixteenth edition. *Now ready.*

Long-Span Railway Bridges, comprising Investigations of the Comparative Theoretical and Practical Advantages of the various adopted or proposed Type Systems of Construction, with numerous Formulæ and Tables giving the weight of Iron or Steel required in Bridges from 300 feet to the limiting Spans; to which are added similar Investigations and Tables relating to Short-span Railway Bridges. Second and revised edition. By B. BAKER, Assoc. Inst. C.E. *Plates,* crown 8vo, cloth, 5*s.*

Elementary Theory and Calculation of Iron Bridges and Roofs. By AUGUST RITTER, Ph.D., Professor at the Polytechnic School at Aix-la-Chapelle. Translated from the third German edition, by H. R. SANKEY, Capt. R.E. With 500 *illustrations,* 8vo, cloth, 15*s.*

The Elementary Principles of Carpentry. By THOMAS TREDGOLD. Revised from the original edition, and partly re-written, by JOHN THOMAS HURST. Contained in 517 pages of letterpress, and *illustrated with* 48 *plates and* 150 *wood engravings.* Sixth edition, reprinted from the third, crown 8vo, cloth, 12*s.* 6*d.*

Section I. On the Equality and Distribution of Forces—Section II. Resistance of Timber—Section III. Construction of Floors—Section IV. Construction of Roofs—Section V. Construction of Domes and Cupolas—Section VI. Construction of Partitions—Section VII. Scaffolds, Staging, and Gantries—Section VIII. Construction of Centres for Bridges—Section IX. Coffer-dams, Shoring, and Strutting—Section X. Wooden Bridges and Viaducts—Section XI. Joints, Straps, and other Fastenings—Section XII. Timber.

The Builder's Clerk: a Guide to the Management of a Builder's Business. By THOMAS BALES. Fcap. 8vo, cloth, 1*s*. 6*d*.

Our Factories, Workshops, and Warehouses: their Sanitary and Fire-Resisting Arrangements. By B. H. THWAITE, Assoc. Mem. Inst. C.E. *With* 183 *wood engravings*, crown 8vo, cloth, 9*s*.

Gold: Its Occurrence and Extraction, embracing the Geographical and Geological Distribution and the Mineralogical Characters of Gold-bearing rocks; the peculiar features and modes of working Shallow Placers, Rivers, and Deep Leads; Hydraulicing; the Reduction and Separation of Auriferous Quartz; the treatment of complex Auriferous ores containing other metals; a Bibliography of the subject and a Glossary of Technical and Foreign Terms. By ALFRED G. LOCK, F.R.G.S. *With numerous illustrations and maps*, 1250 pp., super-royal 8vo, cloth, 2*l*. 12*s*. 6*d*.

Iron Roofs: Examples of Design, Description. *Illustrated with* 64 *Working Drawings of Executed Roofs.* By ARTHUR T. WALMISLEY, Assoc. Mem. Inst. C.E. Second edition, revised, imp. 4to, half-morocco, 3*l*. 3*s*.

A History of Electric Telegraphy, to the Year 1837. Chiefly compiled from Original Sources, and hitherto Unpublished Documents, by J. J. FAHIE, Mem. Soc. of Tel. Engineers, and of the International Society of Electricians, Paris. Crown 8vo, cloth, 9*s*.

Spons' Information for Colonial Engineers. Edited by J. T. HURST. Demy 8vo, sewed.

No. 1, Ceylon. By ABRAHAM DEANE, C.E. 2*s*. 6*d*.

CONTENTS:

Introductory Remarks—Natural Productions—Architecture and Engineering—Topography, Trade, and Natural History—Principal Stations—Weights and Measures, etc., etc.

No. 2. Southern Africa, including the Cape Colony, Natal, and the Dutch Republics. By HENRY HALL, F.R.G.S., F.R.C.I. With Map. 3*s*. 6*d*.

CONTENTS:

General Description of South Africa—Physical Geography with reference to Engineering Operations—Notes on Labour and Material in Cape Colony—Geological Notes on Rock Formation in South Africa—Engineering Instruments for Use in South Africa—Principal Public Works in Cape Colony: Railways, Mountain Roads and Passes, Harbour Works, Bridges, Gas Works, Irrigation and Water Supply, Lighthouses, Drainage and Sanitary Engineering, Public Buildings, Mines—Table of Woods in South Africa—Animals used for Draught Purposes—Statistical Notes—Table of Distances—Rates of Carriage, etc.

No. 3. India. By F. C. DANVERS, Assoc. Inst. C.E. With Map. 4*s*. 6*d*.

CONTENTS:

Physical Geography of India—Building Materials—Roads—Railways—Bridges—Irrigation—River Works—Harbours—Lighthouse Buildings—Native Labour—The Principal Trees of India—Money—Weights and Measures—Glossary of Indian Terms, etc.

A Practical Treatise on Coal Mining. By GEORGE G. ANDRÉ, F.G.S., Assoc. Inst. C.E., Member of the Society of Engineers. *With* 82 *lithographic plates.* 2 vols., royal 4to, cloth, 3*l.* 12*s.*

A Practical Treatise on Casting and Founding, including descriptions of the modern machinery employed in the art. By N. E. SPRETSON, Engineer. Third edition, with 82 *plates* drawn to scale, 412 pp., demy 8vo, cloth, 18*s.*

The Depreciation of Factories and their Valuation. By EWING MATHESON, M. Inst. C.E. 8vo, cloth, 6*s.*

A Handbook of Electrical Testing. By H. R. KEMPE, M.S.T.E. Fourth edition, revised and enlarged, crown 8vo, cloth, 16*s.*

Gas Works: their Arrangement, Construction, Plant, and Machinery. By F. COLYER, M. Inst. C.E. *With* 31 *folding plates*, 8vo, cloth, 24*s.*

The Clerk of Works: a Vade-Mecum for all engaged in the Superintendence of Building Operations. By G. G. HOSKINS, F.R.I.B.A. Third edition, fcap. 8vo, cloth, 1*s.* 6*d.*

American Foundry Practice: Treating of Loam, Dry Sand, and Green Sand Moulding, and containing a Practical Treatise upon the Management of Cupolas, and the Melting of Iron. By T. D. WEST, Practical Iron Moulder and Foundry Foreman. Second edition, *with numerous illustrations*, crown 8vo, cloth, 10*s.* 6*d.*

The Maintenance of Macadamised Roads. By T. CODRINGTON, M.I.C.E, F.G.S., General Superintendent of County Roads for South Wales. 8vo, cloth, 6*s.*

Hydraulic Steam and Hand Power Lifting and Pressing Machinery. By FREDERICK COLYER, M. Inst. C.E., M. Inst. M.E. *With* 73 *plates*, 8vo, cloth, 18*s.*

Pumps and Pumping Machinery. By F. COLYER, M.I.C.E., M.I.M.E. *With* 23 *folding plates*, 8vo, cloth, 12*s.* 6*d.*

Pumps and Pumping Machinery. By F. COLYER. Second Part. *With* 11 *large plates*, 8vo, cloth, 12*s.* 6*d.*

A Treatise on the Origin, Progress, Prevention, and Cure of Dry Rot in Timber; with Remarks on the Means of Preserving Wood from Destruction by Sea-Worms, Beetles, Ants, etc. By THOMAS ALLEN BRITTON, late Surveyor to the Metropolitan Board of Works, etc., etc. *With* 10 *plates*, crown 8vo, cloth, 7*s.* 6*d.*

The Municipal and Sanitary Engineer's Handbook.

By H. PERCY BOULNOIS, Mem. Inst. C.E., Borough Engineer, Portsmouth. *With numerous illustrations*, demy 8vo, cloth, 12*s*. 6*d*.

CONTENTS:

The Appointment and Duties of the Town Surveyor—Traffic—Macadamised Roadways—Steam Rolling—Road Metal and Breaking—Pitched Pavements—Asphalte—Wood Pavements—Footpaths—Kerbs and Gutters—Street Naming and Numbering—Street Lighting—Sewerage—Ventilation of Sewers—Disposal of Sewage—House Drainage—Disinfection—Gas and Water Companies, etc., Breaking up Streets—Improvement of Private Streets—Borrowing Powers—Artizans' and Labourers' Dwellings—Public Conveniences—Scavenging, including Street Cleansing—Watering and the Removing of Snow—Planting Street Trees—Deposit of Plans—Dangerous Buildings—Hoardings—Obstructions—Improving Street Lines—Cellar Openings—Public Pleasure Grounds—Cemeteries—Mortuaries—Cattle and Ordinary Markets—Public Slaughter-houses, etc.—Giving numerous Forms of Notices, Specifications, and General Information upon these and other subjects of great importance to Municipal Engineers and others engaged in Sanitary Work.

Metrical Tables. By G. L. MOLESWORTH, M.I.C.E.

32mo, cloth, 1*s*. 6*d*.

CONTENTS.

General—Linear Measures—Square Measures—Cubic Measures—Measures of Capacity—Weights—Combinations—Thermometers.

Elements of Construction for Electro-Magnets. By

Count TH. DU MONCEL, Mem. de l'Institut de France. Translated from the French by C. J. WHARTON. Crown 8vo, cloth, 4*s*. 6*d*.

Practical Electrical Units Popularly Explained, with

numerous illustrations and Remarks. By JAMES SWINBURNE, late of J. W. Swan and Co., Paris, late of Brush-Swan Electric Light Company, U.S.A. 18mo, cloth, 1*s*. 6*d*.

A Treatise on the Use of Belting for the Transmission of Power.

By J. H. COOPER. Second edition, *illustrated*, 8vo, cloth, 15*s*.

A Pocket-Book of Useful Formulæ and Memoranda for Civil and Mechanical Engineers.

By GUILFORD L. MOLESWORTH, Mem. Inst. C.E., Consulting Engineer to the Government of India for State Railways. *With numerous illustrations*, 744 pp. Twenty-second edition, revised and enlarged, 32mo, roan, 6*s*.

SYNOPSIS OF CONTENTS:

Surveying, Levelling, etc.—Strength and Weight of Materials—Earthwork, Brickwork, Masonry, Arches, etc.—Struts, Columns, Beams, and Trusses—Flooring, Roofing, and Roof Trusses—Girders, Bridges, etc.—Railways and Roads—Hydraulic Formulæ—Canals, Sewers, Waterworks, Docks—Irrigation and Breakwaters—Gas, Ventilation, and Warming—Heat, Light, Colour, and Sound—Gravity: Centres, Forces, and Powers—Millwork, Teeth of Wheels, Shafting, etc.—Workshop Recipes—Sundry Machinery—Animal Power—Steam and the Steam Engine—Water-power, Water-wheels, Turbines, etc.—Wind and Windmills—Steam Navigation, Ship Building, Tonnage, etc.—Gunnery, Projectiles, etc.—Weights, Measures, and Money—Trigonometry, Conic Sections, and Curves—Telegraphy—Mensuration—Tables of Areas and Circumference, and Arcs of Circles—Logarithms, Square and Cube Roots, Powers—Reciprocals, etc.—Useful Numbers—Differential and Integral Calculus—Algebraic Signs—Telegraphic Construction and Formulæ.

Sanitary Engineering: a Guide to the Construction of Works of Sewerage and House Drainage, with Tables for facilitating the calculations of the Engineer. By BALDWIN LATHAM, C.E., M. Inst. C.E., F.G.S., F.M.S., Past-President of the Society of Engineers. Second edition, *with numerous plates and woodcuts*, 8vo, cloth, 1*l.* 10*s.*

Screw Cutting Tables for Engineers and Machinists, giving the values of the different trains of Wheels required to produce Screws of any pitch, calculated by Lord Lindsay, M.P., F.R.S., F.R.A.S., etc. Cloth, oblong, 2*s.*

Screw Cutting Tables, for the use of Mechanical Engineers, showing the proper arrangement of Wheels for cutting the Threads of Screws of any required pitch, with a Table for making the Universal Gas-pipe Threads and Taps. By W. A. MARTIN, Engineer. Second edition, oblong, cloth, 1*s.*, or sewed, 6*d.*

A Treatise on a Practical Method of Designing Slide-Valve Gears by Simple Geometrical Construction, based upon the principles enunciated in Euclid's Elements, and comprising the various forms of Plain Slide-Valve and Expansion Gearing; together with Stephenson's, Gooch's, and Allan's Link-Motions, as applied either to reversing or to variable expansion combinations. By EDWARD J. COWLING WELCH, Memb. Inst. Mechanical Engineers. Crown 8vo, cloth, 6*s.*

Cleaning and Scouring: a Manual for Dyers, Laundresses, and for Domestic Use. By S. CHRISTOPHER. 18mo, sewed, 6*d.*

A Glossary of Terms used in Coal Mining. By WILLIAM STUKELEY GRESLEY, Assoc. Mem. Inst. C.E., F.G.S., Member of the North of England Institute of Mining Engineers. *Illustrated with numerous woodcuts and diagrams*, crown 8vo, cloth, 5*s.*

A Pocket-Book for Boiler Makers and Steam Users, comprising a variety of useful information for Employer and Workman, Government Inspectors, Board of Trade Surveyors, Engineers in charge of Works and Slips, Foremen of Manufactories, and the general Steam-using Public. By MAURICE JOHN SEXTON. Second edition, royal 32mo, roan, gilt edges, 5*s.*

Electrolysis: a Practical Treatise on Nickeling, Coppering, Gilding, Silvering, the Refining of Metals, and the treatment of Ores by means of Electricity. By HIPPOLYTE FONTAINE, translated from the French by J. A. BERLY, C.E., Assoc. S.T.E. *With engravings.* 8vo, cloth, 9*s.*

Barlow's Tables of Squares, Cubes, Square Roots, *Cube Roots, Reciprocals of all Integer Numbers up to* 10,000. Post 8vo, cloth, 6*s.*

A Practical Treatise on the Steam Engine, containing Plans and Arrangements of Details for Fixed Steam Engines, with Essays on the Principles involved in Design and Construction. By ARTHUR RIGG, Engineer, Member of the Society of Engineers and of the Royal Institution of Great Britain. Demy 4to, *copiously illustrated with woodcuts and* 96 *plates*, in one Volume, half-bound morocco, 2*l.* 2*s.*; or cheaper edition, cloth, 25*s.*

This work is not, in any sense, an elementary treatise, or history of the steam engine, but is intended to describe examples of Fixed Steam Engines without entering into the wide domain of locomotive or marine practice. To this end illustrations will be given of the most recent arrangements of Horizontal, Vertical, Beam, Pumping, Winding, Portable, Semi-portable, Corliss, Allen, Compound, and other similar Engines, by the most eminent Firms in Great Britain and America. The laws relating to the action and precautions to be observed in the construction of the various details, such as Cylinders, Pistons, Piston-rods, Connecting-rods, Cross-heads, Motion-blocks, Eccentrics, Simple, Expansion, Balanced, and Equilibrium Slide-valves, and Valve-gearing will be minutely dealt with. In this connection will be found articles upon the Velocity of Reciprocating Parts and the Mode of Applying the Indicator, Heat and Expansion of Steam Governors, and the like. It is the writer's desire to draw illustrations from every possible source, and give only those rules that present practice deems correct.

A Practical Treatise on the Science of Land and *Engineering Surveying, Levelling, Estimating Quantities, etc.*, with a general description of the several Instruments required for Surveying, Levelling, Plotting, etc. By H. S. MERRETT. Fourth edition, revised by G. W. USILL, Assoc. Mem. Inst. C.E. 41 *plates, with illustrations and tables*, royal 8vo, cloth, 12*s.* 6*d.*

PRINCIPAL CONTENTS:

Part 1. Introduction and the Principles of Geometry. Part 2. Land Surveying; comprising General Observations—The Chain—Offsets Surveying by the Chain only—Surveying Hilly Ground—To Survey an Estate or Parish by the Chain only—Surveying with the Theodolite—Mining and Town Surveying—Railroad Surveying—Mapping—Division and Laying out of Land—Observations on Enclosures—Plane Trigonometry. Part 3. Levelling—Simple and Compound Levelling—The Level Book—Parliamentary Plan and Section—Levelling with a Theodolite—Gradients—Wooden Curves—To Lay out a Railway Curve—Setting out Widths. Part 4. Calculating Quantities generally for Estimates—Cuttings and Embankments—Tunnels—Brickwork—Ironwork—Timber Measuring. Part 5. Description and Use of Instruments in Surveying and Plotting—The Improved Dumpy Level—Troughton's Level—The Prismatic Compass—Proportional Compass—Box Sextant—Vernier—Pantagraph—Merrett's Improved Quadrant—Improved Computation Scale—The Diagonal Scale—Straight Edge and Sector. Part 6. Logarithms of Numbers—Logarithmic Sines and Co-Sines, Tangents and Co-Tangents—Natural Sines and Co-Sines—Tables for Earthwork, for Setting out Curves, and for various Calculations, etc., etc., etc.

Health and Comfort in House Building, or Ventilation with Warm Air by Self-Acting Suction Power, with Review of the mode of Calculating the Draught in Hot-Air Flues, and with some actual Experiments. By J. DRYSDALE, M.D., and J. W. HAYWARD, M.D. Second edition, with Supplement, *with plates*, demy 8vo, cloth, 7*s.* 6*d.*

The Assayer's Manual: an Abridged Treatise on the Docimastic Examination of Ores and Furnace and other Artificial Products. By BRUNO KERL. Translated by W. T. BRANNT. *With* 65 *illustrations*, 8vo, cloth, 12*s.* 6*d.*

Electricity: its Theory, Sources, and Applications. By J. T. SPRAGUE, M.S.T.E. Second edition, revised and enlarged, *with numerous illustrations*, crown 8vo, cloth, 15*s.*

The Practice of Hand Turning in Wood, Ivory, Shell, etc., with Instructions for Turning such Work in Metal as may be required in the Practice of Turning in Wood, Ivory, etc.; also an Appendix on Ornamental Turning. (A book for beginners.) By FRANCIS CAMPIN. Third edition, *with wood engravings*, crown 8vo, cloth, 6*s.*

CONTENTS:

On Lathes—Turning Tools—Turning Wood—Drilling—Screw Cutting—Miscellaneous Apparatus and Processes—Turning Particular Forms—Staining—Polishing—Spinning Metals—Materials—Ornamental Turning, etc.

Treatise on Watchwork, Past and Present. By the Rev. H. L. NELTHROPP, M.A., F.S.A. *With* 32 *illustrations*, crown 8vo, cloth, 6*s.* 6*d.*

CONTENTS:

Definitions of Words and Terms used in Watchwork—Tools—Time—Historical Summary—On Calculations of the Numbers for Wheels and Pinions; their Proportional Sizes, Trains, etc.—Of Dial Wheels, or Motion Work—Length of Time of Going without Winding up—The Verge—The Horizontal—The Duplex—The Lever—The Chronometer—Repeating Watches—Keyless Watches—The Pendulum, or Spiral Spring—Compensation—Jewelling of Pivot Holes—Clerkenwell—Fallacies of the Trade—Incapacity of Workmen—How to Choose and Use a Watch, etc.

Algebra Self-Taught. By W. P. HIGGS, M.A., D.Sc., LL.D., Assoc. Inst. C.E., Author of 'A Handbook of the Differential Calculus,' etc. Second edition, crown 8vo, cloth, 2*s.* 6*d.*

CONTENTS:

Symbols and the Signs of Operation—The Equation and the Unknown Quantity—Positive and Negative Quantities—Multiplication—Involution—Exponents—Negative Exponents—Roots, and the Use of Exponents as Logarithms—Logarithms—Tables of Logarithms and Proportionate Parts—Transformation of System of Logarithms—Common Uses of Common Logarithms—Compound Multiplication and the Binomial Theorem—Division, Fractions, and Ratio—Continued Proportion—The Series and the Summation of the Series—Limit of Series—Square and Cube Roots—Equations—List of Formulæ, etc.

Spons' Dictionary of Engineering, Civil, Mechanical, Military, and Naval: with technical terms in French, German, Italian, and Spanish, 3100 pp., and *nearly* 8000 *engravings*, in super-royal 8vo, in 8 divisions, 5*l.* 8*s.* Complete in 3 vols., cloth, 5*l.* 5*s.* Bound in a superior manner, half-morocco, top edge gilt, 3 vols., 6*l.* 12*s.*

Notes in Mechanical Engineering. Compiled principally for the use of the Students attending the Classes on this subject at the City of London College. By HENRY ADAMS, Mem. Inst. M.E., Mem. Inst. C.E., Mem. Soc. of Engineers. Crown 8vo, cloth, 2s. 6d.

Canoe and Boat Building: a complete Manual for Amateurs, containing plain and comprehensive directions for the construction of Canoes, Rowing and Sailing Boats, and Hunting Craft. By W. P. STEPHENS. *With numerous illustrations and 24 plates of Working Drawings.* Crown 8vo, cloth, 7s. 6d.

Proceedings of the National Conference of Electricians, Philadelphia, October 8th to 13th, 1884. 18mo, cloth, 3s.

Dynamo-Electricity, its Generation, Application, Transmission, Storage, and Measurement. By G. B. PRESCOTT. *With 545 illustrations.* 8vo, cloth, 1*l.* 1s.

Domestic Electricity for Amateurs. Translated from the French of E. HOSPITALIER, Editor of "L'Electricien," by C. J. WHARTON, Assoc. Soc. Tel. Eng. *Numerous illustrations.* Demy 8vo, cloth, 9s.

CONTENTS:

1. Production of the Electric Current—2. Electric Bells—3. Automatic Alarms—4. Domestic Telephones—5. Electric Clocks—6. Electric Lighters—7. Domestic Electric Lighting—8. Domestic Application of the Electric Light—9. Electric Motors—10. Electrical Locomotion—11. Electrotyping, Plating, and Gilding—12. Electric Recreations—13. Various applications—Workshop of the Electrician.

Wrinkles in Electric Lighting. By VINCENT STEPHEN. *With illustrations.* 18mo, cloth, 2s. 6d.

CONTENTS:

1. The Electric Current and its production by Chemical means—2. Production of Electric Currents by Mechanical means—3. Dynamo-Electric Machines—4. Electric Lamps—5. Lead—6. Ship Lighting.

The Practical Flax Spinner; being a Description of the Growth, Manipulation, and Spinning of Flax and Tow. By LESLIE C. MARSHALL, of Belfast. *With illustrations.* 8vo, cloth, 15s.

Foundations and Foundation Walls for all classes of Buildings, Pile Driving, Building Stones and Bricks, Pier and Wall construction, Mortars, Limes, Cements, Concretes, Stuccos, &c. 64 *illustrations.* By G. T. POWELL and F. BAUMAN. 8vo, cloth, 10s. 6d.

Manual for Gas Engineering Students. By D. Lee. 18mo, cloth 1*s.*

Hydraulic Machinery, Past and Present. A Lecture delivered to the London and Suburban Railway Officials' Association. By H. Adams, Mem. Inst. C.E. *Folding plate.* 8vo, sewed, 1*s.*

Twenty Years with the Indicator. By Thomas Pray, Jun., C.E., M.E., Member of the American Society of Civil Engineers. 2 vols., royal 8vo, cloth, 12*s.* 6*d.*

Annual Statistical Report of the Secretary to the Members of the Iron and Steel Association on the Home and Foreign Iron and Steel Industries in 1884. Issued March 1885. 8vo, sewed, 5*s.*

Bad Drains, and How to Test them; with Notes on the Ventilation of Sewers, Drains, and Sanitary Fittings, and the Origin and Transmission of Zymotic Disease. By R. Harris Reeves. Crown 8vo, cloth, 3*s.* 6*d.*

Well Sinking. The modern practice of Sinking and Boring Wells, with geological considerations and examples of Wells. By Ernest Spon, Assoc. Mem. Inst. C.E., Mem. Soc. Eng., and of the Franklin Inst., etc. Second edition, revised and enlarged. Crown 8vo, cloth, 10*s.* 6*d.*

Pneumatic Transmission of Messages and Parcels between Paris and London, viâ Calais and Dover. By J. B. Berlier, C.E. Small folio, sewed, 6*d.*

List of Tests (*Reagents*), arranged in alphabetical order, according to the names of the originators. Designed especially for the convenient reference of Chemists, Pharmacists, and Scientists. By Hans M. Wilder. Crown 8vo, cloth, 4*s.* 6*d.*

Ten Years' Experience in Works of Intermittent Downward Filtration. By J. Bailey Denton, Mem. Inst. C.E. Second edition, with additions. Royal 8vo, sewed, 4*s.*

A Treatise on the Manufacture of Soap and Candles, Lubricants and Glycerin. By W. Lant Carpenter, B.A., B.Sc. (late of Messrs. C. Thomas and Brothers, Bristol). *With illustrations.* Crown cloth, 10*s.* 6*d.*

The Stability of Ships explained simply, and calculated by a new Graphic method. By J. C. SPENCE, M.I.N.A. 4to, sewed, 3*s*. 6*d*.

Steam Making, or Boiler Practice. By CHARLES A. SMITH, C.E. 8vo, cloth, 10*s*. 6*d*.

CONTENTS:

1. The Nature of Heat and the Properties of Steam—2. Combustion.—3. Externally Fired Stationary Boilers—4. Internally Fired Stationary Boilers—5. Internally Fired Portable Locomotive and Marine Boilers—6. Design, Construction, and Strength of Boilers—7. Proportions of Heating Surface, Economic Evaporation, Explosions—8. Miscellaneous Boilers, Choice of Boiler Fittings and Appurtenances.

The Fireman's Guide; a Handbook on the Care of Boilers. By TEKNOLOG, föreningen T. I. Stockholm. Translated from the third edition, and revised by KARL P. DAHLSTROM, M.E. Second edition. Fcap. 8vo, cloth, 2*s*.

A Treatise on Modern Steam Engines and Boilers, including Land Locomotive, and Marine Engines and Boilers, for the use of Students. By FREDERICK COLYER, M. Inst. C.E., Mem. Inst. M.E. *With* 36 *plates.* 4to, cloth, 25*s*.

CONTENTS:

1. Introduction—2. Original Engines—3. Boilers—4. High-Pressure Beam Engines—5. Cornish Beam Engines—6. Horizontal Engines—7. Oscillating Engines—8. Vertical High-Pressure Engines—9. Special Engines—10. Portable Engines—11. Locomotive Engines—12. Marine Engines.

Steam Engine Management; a Treatise on the Working and Management of Steam Boilers. By F. COLYER, M. Inst. C.E., Mem. Inst. M.E. 18mo, cloth, 2*s*.

Land Surveying on the Meridian and Perpendicular System. By WILLIAM PENMAN, C.E. 8vo, cloth, 8*s*. 6*d*.

The Topographer, his Instruments and Methods, designed for the use of Students, Amateur Photographers, Surveyors, Engineers, and all persons interested in the location and construction of works based upon Topography. *Illustrated with numerous plates, maps, and engravings.* By LEWIS M. HAUPT, A.M. 8vo, cloth, 18*s*.

A Text-Book of Tanning, embracing the Preparation of all kinds of Leather. By HARRY R. PROCTOR, F.C.S., of Low Lights Tanneries. *With illustrations.* Crown 8vo, cloth, 10*s*. 6*d*.

In super-royal 8vo, 1168 pp., *with 2400 illustrations*, in 3 Divisions, cloth, price 13*s*. 6*d*. each; or 1 vol., cloth, 2*l*.; or half-morocco, 2*l*. 8*s*.

A SUPPLEMENT

TO

SPONS' DICTIONARY OF ENGINEERING.

EDITED BY ERNEST SPON, MEMB. SOC. ENGINEERS.

Abacus, Counters, Speed Indicators, and Slide Rule.
Agricultural Implements and Machinery.
Air Compressors.
Animal Charcoal Machinery.
Antimony.
Axles and Axle-boxes.
Barn Machinery.
Belts and Belting.
Blasting. Boilers.
Brakes.
Brick Machinery.
Bridges.
Cages for Mines.
Calculus, Differential and Integral.
Canals.
Carpentry.
Cast Iron.
Cement, Concrete, Limes, and Mortar.
Chimney Shafts.
Coal Cleansing and Washing.
Coal Mining.
Coal Cutting Machines.
Coke Ovens. Copper.
Docks. Drainage.
Dredging Machinery.
Dynamo - Electric and Magneto-Electric Machines.
Dynamometers.
Electrical Engineering, Telegraphy, Electric Lighting and its practical details, Telephones
Engines, Varieties of.
Explosives. Fans.
Founding, Moulding and the practical work of the Foundry.
Gas, Manufacture of.
Hammers, Steam and other Power.
Heat. Horse Power.
Hydraulics.
Hydro-geology.
Indicators. Iron.
Lifts, Hoists, and Elevators.
Lighthouses, Buoys, and Beacons.
Machine Tools.
Materials of Construction.
Meters.
Ores, Machinery and Processes employed to Dress.
Piers.
Pile Driving.
Pneumatic Transmission.
Pumps.
Pyrometers.
Road Locomotives.
Rock Drills.
Rolling Stock.
Sanitary Engineering.
Shafting.
Steel.
Steam Navvy.
Stone Machinery.
Tramways.
Well Sinking.

London: E. & F. N. SPON, 125, Strand.
New York: 12, Cortlandt Street.

NOW COMPLETE.

With nearly 1500 *illustrations*, in super-royal 8vo, in 5 Divisions, cloth Divisions 1 to 4, 13*s*. 6*d*. each; Division 5, 17*s*. 6*d*.; or 2 vols., cloth, £3 10*s*.

SPONS' ENCYCLOPÆDIA
OF THE
INDUSTRIAL ARTS, MANUFACTURES, AND COMMERCIAL PRODUCTS.

EDITED BY C. G. WARNFORD LOCK, F.L.S.

Among the more important of the subjects treated of, are the following:—

Acids, 207 pp. 220 figs.
Alcohol, 23 pp. 16 figs.
Alcoholic Liquors, 13 pp.
Alkalies, 89 pp. 78 figs.
Alloys. Alum.
Asphalt. Assaying.
Beverages, 89 pp. 29 figs.
Blacks.
Bleaching Powder, 15 pp.
Bleaching, 51 pp. 48 figs.
Candles, 18 pp. 9 figs.
Carbon Bisulphide.
Celluloid, 9 pp.
Cements. Clay.
Coal-tar Products, 44 pp. 14 figs.
Cocoa, 8 pp.
Coffee, 32 pp. 13 figs.
Cork, 8 pp. 17 figs.
Cotton Manufactures, 62 pp. 57 figs.
Drugs, 38 pp.
Dyeing and Calico Printing, 28 pp. 9 figs.
Dyestuffs, 16 pp.
Electro-Metallurgy, 13 pp.
Explosives, 22 pp. 33 figs.
Feathers.
Fibrous Substances, 92 pp. 79 figs.
Floor-cloth, 16 pp. 21 figs.
Food Preservation, 8 pp.
Fruit, 8 pp.
Fur, 5 pp.
Gas, Coal, 8 pp.
Gems.
Glass, 45 pp. 77 figs.
Graphite, 7 pp.
Hair, 7 pp.
Hair Manufactures.
Hats, 26 pp. 26 figs.
Honey. Hops.
Horn.
Ice, 10 pp. 14 figs.
Indiarubber Manufactures, 23 pp. 17 figs.
Ink, 17 pp.
Ivory.
Jute Manufactures, 11 pp., 11 figs.
Knitted Fabrics — Hosiery, 15 pp. 13 figs.
Lace, 13 pp. 9 figs.
Leather, 28 pp. 31 figs.
Linen Manufactures, 16 pp. 6 figs.
Manures, 21 pp. 30 figs.
Matches, 17 pp. 38 figs.
Mordants, 13 pp.
Narcotics, 47 pp.
Nuts, 10 pp.
Oils and Fatty Substances, 125 pp.
Paint.
Paper, 26 pp. 23 figs.
Paraffin, 8 pp. 6 figs.
Pearl and Coral, 8 pp.
Perfumes, 10 pp.
Photography, 13 pp. 20 figs.
Pigments, 9 pp. 6 figs.
Pottery, 46 pp. 57 figs.
Printing and Engraving, 20 pp. 8 figs.
Rags.
Resinous and Gummy Substances, 75 pp. 16 figs.
Rope, 16 pp. 17 figs.
Salt, 31 pp. 23 figs.
Silk, 8 pp.
Silk Manufactures, 9 pp. 11 figs.
Skins, 5 pp.
Small Wares, 4 pp.
Soap and Glycerine, 39 pp. 45 figs.
Spices, 16 pp.
Sponge, 5 pp.
Starch, 9 pp. 10 figs.
Sugar, 155 pp. 134 figs.
Sulphur.
Tannin, 18 pp.
Tea, 12 pp.
Timber, 13 pp.
Varnish, 15 pp.
Vinegar, 5 pp.
Wax, 5 pp.
Wool, 2 pp.
Woollen Manufactures, 58 pp. 39 figs.

London: E. & F. N. SPON, 125, Strand.
New York: 12, Cortlandt Street.

Crown 8vo, cloth, with illustrations, 5*s.*

WORKSHOP RECEIPTS,

FIRST SERIES.

BY ERNEST SPON.

SYNOPSIS OF CONTENTS.

Bookbinding.
Bronzes and Bronzing.
Candles.
Cement.
Cleaning.
Colourwashing.
Concretes.
Dipping Acids.
Drawing Office Details.
Drying Oils.
Dynamite.
Electro - Metallurgy — (Cleaning, Dipping, Scratch-brushing, Batteries, Baths, and Deposits of every description).
Enamels.
Engraving on Wood, Copper, Gold, Silver, Steel, and Stone.
Etching and Aqua Tint.
Firework Making — (Rockets, Stars, Rains, Gerbes, Jets, Tourbillons, Candles, Fires, Lances, Lights, Wheels, Fire-balloons, and minor Fireworks).
Fluxes.
Foundry Mixtures.
Freezing.
Fulminates.
Furniture Creams, Oils, Polishes, Lacquers, and Pastes.
Gilding.
Glass Cutting, Cleaning, Frosting, Drilling, Darkening, Bending, Staining, and Painting.
Glass Making.
Glues.
Gold.
Graining.
Gums.
Gun Cotton.
Gunpowder.
Horn Working.
Indiarubber.
Japans, Japanning, and kindred processes.
Lacquers.
Lathing.
Lubricants.
Marble Working.
Matches.
Mortars.
Nitro-Glycerine.
Oils.
Paper.
Paper Hanging.
Painting in Oils, in Water Colours, as well as Fresco, House, Transparency, Sign, and Carriage Painting.
Photography.
Plastering.
Polishes.
Pottery—(Clays, Bodies, Glazes, Colours, Oils, Stains, Fluxes, Enamels, and Lustres).
Scouring.
Silvering.
Soap.
Solders.
Tanning.
Taxidermy.
Tempering Metals.
Treating Horn, Mother-o'-Pearl, and like substances.
Varnishes, Manufacture and Use of.
Veneering.
Washing.
Waterproofing.
Welding.

Besides Receipts relating to the lesser Technological matters and processes, such as the manufacture and use of Stencil Plates, Blacking, Crayons, Paste, Putty, Wax, Size, Alloys, Catgut, Tunbridge Ware, Picture Frame and Architectural Mouldings, Compos, Cameos, and others too numerous to mention.

London: E. & F. N. SPON, 125, Strand.
New York: 12, Cortlandt Street.

Crown 8vo, cloth, 485 pages, with illustrations, 5*s*.

WORKSHOP RECEIPTS,

SECOND SERIES.

BY ROBERT HALDANE.

SYNOPSIS OF CONTENTS.

Acidimetry and Alkalimetry.
Albumen.
Alcohol.
Alkaloids.
Baking-powders.
Bitters.
Bleaching.
Boiler Incrustations.
Cements and Lutes.
Cleansing.
Confectionery.
Copying.
Disinfectants.
Dyeing, Staining, and Colouring.
Essences.
Extracts.
Fireproofing.
Gelatine, Glue, and Size.
Glycerine.
Gut.
Hydrogen peroxide.
Ink.
Iodine.
Iodoform.
Isinglass.
Ivory substitutes.
Leather.
Luminous bodies.
Magnesia.
Matches.
Paper.
Parchment.
Perchloric acid.
Potassium oxalate.
Preserving.

Pigments, Paint, and Painting: embracing the preparation of *Pigments*, including alumina lakes, blacks (animal, bone, Frankfort, ivory, lamp, sight, soot), blues (antimony, Antwerp, cobalt, cæruleum, Egyptian, manganate, Paris, Péligot, Prussian, smalt, ultramarine), browns (bistre, hinau, sepia, sienna, umber, Vandyke), greens (baryta, Brighton, Brunswick, chrome, cobalt, Douglas, emerald, manganese, mitis, mountain, Prussian, sap, Scheele's, Schweinfurth, titanium, verdigris, zinc), reds (Brazilwood lake, carminated lake, carmine, Cassius purple, cobalt pink, cochineal lake, colcothar, Indian red, madder lake, red chalk, red lead, vermilion), whites (alum, baryta, Chinese, lead sulphate, white lead—by American, Dutch, French, German, Kremnitz, and Pattinson processes, precautions in making, and composition of commercial samples—whiting, Wilkinson's white, zinc white), yellows (chrome, gamboge, Naples, orpiment, realgar, yellow lakes); *Paint* (vehicles, testing oils, driers, grinding, storing, applying, priming, drying, filling, coats, brushes, surface, water-colours, removing smell, discoloration; miscellaneous paints—cement paint for carton-pierre, copper paint, gold paint, iron paint, lime paints, silicated paints, steatite paint, transparent paints, tungsten paints, window paint, zinc paints); *Painting* (general instructions, proportions of ingredients, measuring paint work; carriage painting—priming paint, best putty, finishing colour, cause of cracking, mixing the paints, oils, driers, and colours, varnishing, importance of washing vehicles, re-varnishing, how to dry paint; woodwork painting).

London: E. & F. N. SPON, 125, Strand.
New York: 12, Cortlandt Street.

JUST PUBLISHED.

Crown 8vo, cloth, 480 pages, with 183 illustrations, 5*s.*

WORKSHOP RECEIPTS,

THIRD SERIES.

By C. G. WARNFORD LOCK.

Uniform with the First and Second Series.

SYNOPSIS OF CONTENTS.

- Alloys.
- Aluminium.
- Antimony.
- Barium.
- Beryllium.
- Bismuth.
- Cadmium.
- Cæsium.
- Calcium.
- Cerium.
- Chromium.
- Cobalt.
- Copper.
- Didymium.
- Electrics.
- Enamels and Glazes.
- Erbium.
- Gallium.
- Glass.
- Gold.
- Indium.
- Iridium.
- Iron and Steel.
- Lacquers and Lacquering.
- Lanthanum.
- Lead.
- Lithium.
- Lubricants.
- Magnesium.
- Manganese.
- Mercury.
- Mica.
- Molybdenum.
- Nickel.
- Niobium.
- Osmium.
- Palladium.
- Platinum.
- Potassium.
- Rhodium.
- Rubidium.
- Ruthenium.
- Selenium.
- Silver.
- Slag.
- Sodium.
- Strontium.
- Tantalum.
- Terbium.
- Thallium.
- Thorium.
- Tin.
- Titanium.
- Tungsten.
- Uranium.
- Vanadium.
- Yttrium.
- Zinc.
- Zirconium.

London: E. & F. N. SPON, 125, Strand.
New York: 12, Cortlandt Street.

WORKSHOP RECEIPTS,

FOURTH SERIES,

DEVOTED MAINLY TO HANDICRAFTS & MECHANICAL SUBJECTS.

BY C. G. WARNFORD LOCK.

250 Illustrations, with Complete Index, and a General Index to the Four Series, 5s.

Waterproofing—rubber goods, cuprammonium processes, miscellaneous preparations.

Packing and Storing articles of delicate odour or colour, of a deliquescent character, liable to ignition, apt to suffer from insects or damp, or easily broken.

Embalming and Preserving anatomical specimens.

Leather Polishes.

Cooling Air and Water, producing low temperatures, making ice, cooling syrups and solutions, and separating salts from liquors by refrigeration.

Pumps and Siphons, embracing every useful contrivance for raising and supplying water on a moderate scale, and moving corrosive, tenacious, and other liquids.

Desiccating—air- and water-ovens, and other appliances for drying natural and artificial products.

Distilling—water, tinctures, extracts, pharmaceutical preparations, essences, perfumes, and alcoholic liquids.

Emulsifying as required by pharmacists and photographers.

Evaporating—saline and other solutions, and liquids demanding special precautions.

Filtering—water, and solutions of various kinds.

Percolating and Macerating.

Electrotyping.

Stereotyping by both plaster and paper processes.

Bookbinding in all its details.

Straw Plaiting and the fabrication of baskets, matting, etc.

Musical Instruments—the preservation, tuning, and repair of pianos, harmoniums, musical boxes, etc.

Clock and Watch Mending—adapted for intelligent amateurs.

Photography—recent development in rapid processes, handy apparatus, numerous recipes for sensitizing and developing solutions, and applications to modern illustrative purposes.

London: E. & F. N. SPON, 125, Strand.
New York: 12, Cortlandt Street.

JUST PUBLISHED.

In demy 8vo, cloth, 600 pages, and 1420 Illustrations, 6*s*.

SPONS'
MECHANICS' OWN BOOK;
A MANUAL FOR HANDICRAFTSMEN AND AMATEURS.

CONTENTS.

Mechanical Drawing—Casting and Founding in Iron, Brass, Bronze, and other Alloys—Forging and Finishing Iron—Sheetmetal Working—Soldering, Brazing, and Burning—Carpentry and Joinery, embracing descriptions of some 400 Woods, over 200 Illustrations of Tools and their uses, Explanations (with Diagrams) of 116 joints and hinges, and Details of Construction of Workshop appliances, rough furniture, Garden and Yard Erections, and House Building—Cabinet-Making and Veneering—Carving and Fretcutting—Upholstery—Painting, Graining, and Marbling—Staining Furniture, Woods, Floors, and Fittings—Gilding, dead and bright, on various grounds—Polishing Marble, Metals, and Wood—Varnishing—Mechanical movements, illustrating contrivances for transmitting motion—Turning in Wood and Metals—Masonry, embracing Stonework, Brickwork, Terracotta, and Concrete—Roofing with Thatch, Tiles, Slates, Felt, Zinc, &c.—Glazing with and without putty, and lead glazing—Plastering and Whitewashing—Paper-hanging—Gas-fitting—Bell-hanging, ordinary and electric Systems—Lighting—Warming—Ventilating—Roads, Pavements, and Bridges—Hedges, Ditches, and Drains—Water Supply and Sanitation—Hints on House Construction suited to new countries.

London: E. & F. N. SPON, 125, Strand.
New York: 12, Cortlandt Street.